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This is a pre print version of the following article:
Original Citation:
Availability:
This version is available http://hdl.handle.net/2318/1529965 since 2016-06-29T13:45:07Z
Published version:
DOI:10.1016/j.palaeo.2015.09.038
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# UNIVERSITÀ DEGLI STUDI DI TORINO

*This is an author version of the contribution published on (Questa è la versione dell'autore dell'opera*):

TEODORIDIS, V., BRUCH, A.A., VASSIO, E., MARTINETTO, E., KVAČEK, Z., STUCHLIK, L., 2015 in press. Plio-Pleistocene floras of the Vildštejn Formation in the Cheb Basin, Czech Republic – a floristic and palaeoenvironmental review, Palaeogeography, Palaeoclimatology, Palaeoecology.

doi: http://dx.doi.org/10.1016/j.palaeo.2015.09.038

*The definitive version is available at: La versione definitiva è disponibile alla URL: c.els-cdn.com/S0031018215005489/1-s2.0-S0031018215005489 main.pdf?\_tid=7f2aae62-9460-11e5-8026-00000aab0f6b&acdnat=1448557967\_43f4c1fb23e102e059ab182933d9b4f7* 

## 1 Plio-Pleistocene floras of the Vildštejn Formation in the Cheb Basin, Czech Republic – a

## 2 floristic and palaeoenvironmental review

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- 19 Abstract

20 Fossil plant assemblages (foliage, fruits and seeds, pollen, wood) from the Pliocene and early Pleistocene deposits in W Bohemia (the Vildštejn Formation of the Cheb Basin, Tachov 21 /Cheb–Domažlice/ Graben) are newly analysed using several palaeoenvironmental methods 22 aiming at reconstructing palaeovegetation and palaeoclimatic changes. Floras of four 23 24 subsequent stratigraphic levels show a decreasing representation of exotic elements in the 25 Pliocene and a massive immigration of boreal elements in the Early Pleistocene. Vegetation 26 changes start with broad-leaved deciduous and mixed mesophytic forests (BLDF, MMF) and 27 continue to "more open" light forests of BLDF or MMF types in areas of zonal to extrazonal uplands. This vegetational change is characterised by an immigration of dry herbaceous and 28 sclerophyllous elements. Wetland communities stepwise loose exotic components and point 29 to cool-temperate conditions similar to the present higher in the profiles. Palaeoclimatic 30 31 signals show warmer and more humid conditions for the Pliocene levels (about 15°C of mean annual temperature, 5°C of mean winter and 25°C of mean summer temperature, more than 32 900 mm of mean annual precipitation). Early Pleistocene proxy data indicate the beginning 33 of a cooler phase at the Plio-Pleistocene boundary (about 7°C of mean annual temperature 34 35 and decreasing trend of precipitation), but no colder conditions than the present day in the 36 NW part of the Bohemian Massif.

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38 **Key words:** flora; vegetation; palaeoclimate; Pliocene; Pleistocene; Czech Republic

39

40 1. Introduction

41 Plant assemblages (foliage, fruits and seeds, pollen, wood) obtained from drill cores and outcrops of the Vildštejn Formation in the Cheb Basin and the Tachov (Cheb–Domažlice) 42 Graben in western Bohemia were assigned by Bůžek et al. (1985) to the Pliocene-Pleistocene 43 transition, according to the stratigraphic scheme of Gibbard et al. (2010). The fossils have 44 been known since pioneer studies by Karl Rudolph in 1935 and were more systematically 45 46 evaluated by Č. Bůžek, Z. Kvaček, F. Holý, M. Konzalová, and L. Stuchlik from 1982 to 1991 47 (Rudolph, 1935; Bůžek et al., 1982, 1985; Stuchlik, 1982, unpublished). In the present paper the plant material described so far (Bůžek et al., 1985; Stuchlik, 1982) is re-evaluated in 48 current taxonomical context (EM, ZK, VT) and results of subsequently analysed new pollen 49 material (Stuchlik, unpublished) are added (AAB, LS). Several palaeoenvironmental 50 techniques are applied on the complete fossil plant spectra from the Vildštejn Formation 51 52 (Cheb Basin) and relicts of Neogene deposits of the Tachov (Cheb–Domažlice) Graben to 53 reconstruct models of vegetation and climatic changes from the Late Pliocene to Early 54 Pleistocene. The evaluation of the zonal vegetation at the studied sites was conducted using a semi-quantitative method of the Integrated Plant Record vegetation analysis (VT). This 55 56 technique was originally designed to reconstruct the character of zonal vegetation under 57 subtropical to temperate climate. Here for the first time, the IPR-vegetation analysis is applied on Plio-Pleistocene floras originated partly under cool-temperate conditions. The 58 59 obtained results are discussed in the context of those derived from other palaeovegetational techniques allowing to reconstruct complex qualitative and quantitative characteristics of 60 the fossil vegetation, i.e., Phytosociological approach (ZK, VT) and Plant Community Scenario 61 62 approach (EV, EM). Similarly, the multi-technique approach was used to detect climatic

63 changes during the sedimentation of the Vildštejn Formation and the Tachov (Cheb-Domažlice) Graben. The method of the Coexistence Approach (AAB) assesses palaeoclimatic 64 estimates based on the analysis of the micro- and macrofossil plant material. The second 65 palaeoclimatic technique is the physiognomic method of the Leaf Margin Analysis (VT). Its 66 application is strongly limited by the scarcity of the leaf material at the studied sites. 67 68 Therefore we experimentally used also elements from carpological material and estimated 69 characters of the leaf lamina (entire vs. non-entire) based on their nearest living relatives (NLRs). The obtained climatic datasets and CA results are discussed within the frame of 70 71 palaeoclimatic data obtained for other Late Pliocene and Early Pleistocene floras of Europe.

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#### 73 2. Geological setting

The Cheb Basin, the westernmost lignite basin within the Ohře (Eger) Graben lies on a 74 75 tectonic crossing of two major structures – the Ohře (Eger) Rift of WSW-ENE direction (Ziegler, 1990) and a younger structure of the Tachov (Cheb–Domažlice) Graben trending in 76 77 NNW-SSE direction (e.g., Rojík et al., 2010; Fig. 1a). Its sedimentary filling consists of several lithostratigraphic units (formations or levels), partly informally defined, deposited in the 78 79 time interval from Late Eocene to Pliocene-Pleistocene (e.g., Ambrož, 1958; Václ, 1979; Bůžek, et al. 1982; Bucha et al., 1990; Špičáková et al., 2000; Kvaček and Teodoridis, 2007; 80 Rojík et al., 2010). Besides the formally defined formations of Staré Sedlo (Late Eocene), 81 82 Cypris (late Early Miocene) and Vildštejn (Plio-Pleistocene), the other lithostratigraphic units, 83 i.e., the Lower Clay and Sand with the Lower Coal Seam and the Main Coal Seam are

84 informally defined. Recently, Špičáková et al. (2000) described a detailed tectonosedimentary evaluation of the Cheb Basin and the Tachov (Cheb–Domažlice) Graben 85 focusing on three main depositional units only, i.e., the Lower Clay and Sand and Main Coal 86 87 units, Cypris Formation and Vildštejn Formation. Rojík et al. (2010) and Kvaček and 88 Teodoridis (2007) reviewed most of the so far published palaeobotanical data from the Cheb 89 Basin with details of the geological positions. The present account will concentrate only on 90 the youngest part of the basin fill, the Vildštejn Formation. This cycle of fluvio-lacustrine sediments was deposited after a hiatus lasting for about 12 million years partly on the Early 91 92 Miocene Cypris Formation or on crystalline and granitic basement near the western border of the basin. The average thickness of the Vildštejn Formation usually varies from 30 to 60 93 m, but the maximal value exceeds 100 m at the Mariánské Lázně fault belonging to the 94 95 tectonic system of the Tachov (Cheb–Domažlice) Graben. The Vildštejn Formation is divided into two members. The older Vonšov Member is well developed near the villages of Skalná 96 97 (formerly Vildštejn or Wildstein) and Vonšov (formerly Fonsau) and represents weathered illite green clay (partly reworked Cypris claystone), grey-violet or reddish tough clay (Blauton 98 99 D) and tough blue-grey pelite associated with kaolinite. Towards the East and North of the 100 basin, sandy deposits start to occur and intermix with pelitic deposits. The younger Nová Ves Member represents a relatively heterogeneous sequence of layers with a total thickness of 101 102 20 to 50 m. The basal part is characterised by a thick layer of the dark to black clay (called 103 Nero), which is accompanied by lignitic peat horizons in its uppermost part (Nová Ves clay 104 pit) that form the overlying Upper Coal Seam (Václ, 1979), which typically include sandy and 105 mica laminations. According to Bůžek et al. (1985, p. 10), the Nero Clay, generally regarded

106 as a basal layer of the Nová Ves Member (Fig. 1), belongs rather to the sedimentary cycle of the Vonšov Member because this clay deposit is coarser, rich in mica and contains only 107 kaolinite with less ordered structure and lower content of molecular water like clays of the 108 109 Vonšov Member. Pure ball clays are whitish (except the Nero Clay) and form layers mostly in 110 the lower part of the Nová Ves Member. The upper part is characterised by prevailing 111 psammitic sediments. According to Bůžek et al. (1985), the uppermost part of the Nová Ves 112 Member (Overlying sands and gravels sensu Ambrož, 1958; horizon D in this paper) surely represents an independent sedimentary cycle (Fig. 1a, b). 113

The Tachov (Cheb–Domažlice) Graben is partly filled by Neogene deposits which have been 114 115 interpreted as fluviatile sediments of "the river F" sensu Pešek and Spudil (1986). This river system probably drained the western part of the Czech Republic towards the Cheb Basin 116 during the Pliocene (Pešek and Spudil, 1986; Malkovský, 1995). The studied plant macro- and 117 118 microfossils are known from the V1 and V2 drill cores and the Nová Hospoda clay pit (Fig. 119 1a). The geological section of the drill cores, as described by Nosek (1978), consists of about 10 m thick clayey sediments with thin lignitic beds and brown clays that interchange with 120 kaolinitic clays and claystones. This fossiliferous part (mainly clayey horizons) is overlain by 5 121 122 m thick reddish weathered deposits (Bůžek et al., 1985). Pollen material was obtained from 123 the Nová Hospoda clay pit (Gabrielová et al., 1970; Konzalová in Bůžek et al., 1985).

Exact dating of fossiliferous deposits of the Vildštejn Formation and the Tachov (Cheb–
Domažlice) Graben is not always available (Fig. 1b). The palaeomagnetic records derived
from the drill cores of NK-24 and NK-25 (Nový Kostel) suppose a time range from 4.7 to 1.4
Ma (Bucha et al., 1990), although these datasets must be taken just as rough estimates

128 (Špičáková et al., 2000, pp. 561-562; Matys-Grygar, pers. comm. 2013). Špičáková et al.

(2000) present a time range from 4.5 to 1.5 Ma for the deposition of the Vildštejn Formationas a whole.

131

#### 132 **3. Material**

133 Due to the scarcity of outcrops (mainly the Nová Ves, Vonšov and Nová Hospoda clay pits),

the majority of plant material studied derives from drill cores generally situated in the NE

part of the Cheb Basin (Fig. 1). The present study aims at re-evaluating all macrofossil as well

as microfossil (palynological) material described by Bůžek et al. (1985). In addition, new

pollen datasets from the drill core HV 2 and the Nová Ves clay pit (Fig. 2, Appendix 1) are

138 provided. These data are the first quantitative pollen data published for this region and

allow for a more detailed analysis of vegetation and climate changes.

The study follows the original concept of fossiliferous horizons within the Vildštejn
Formation given by Bůžek et al. (1985) and recognizes four stratigraphic levels for
quantitative analyses:

(1) Vonšov Member (Fig. 1; Table 1 – marked as B, or I.) – this level includes macrofossil
floras from the drill core HV 9, and pollen data from the lower part of the Nová Ves clay pit
(levels A1-A3) and the lower part of drill cores HV 2 and HV 3 (Stuchlik, 1982). Due to the
sandy facies in drill cores HV 2 and HV 3 the stratigraphic boundaries between the Vonšov
and Nová Ves members cannot be clearly fixed. They were characterised by Stuchlik (1982)

148 by comparing the palynological assemblages with data from the Nová Ves clay pit. The 149 middle parts of drill cores HV 2 and HV 3 show abundant occurrences of Alnus and other riparian and wetland elements (Salix, Nyssa, Cyperaceae, etc.) as well as significant 150 occurrences of Betula, Corylus, and Myrica, and are comparable with part "A" (Pluto Clay) of 151 152 the Nová Ves clay pit (Stuchlik, 1982). The original pollen material collected by Stuchlik from 153 the drill core HV 2 and the Nová Ves clay pit was re-studied by us (Appendix 1). Pollen 154 datasets from drill core HV 3 were not available. Although a clear position of the boundary between the Pluto and Nero clays is not given by Stuchlik (1982) and correlation of the 155 156 pollen diagrams remains vague, we assign pollen samples from the depths of 35.3 m to 55.2 157 m to the Pluto Clay in the drill core HV 2 (Bůžek et al., 1985, Fig. 2) based on the above 158 mentioned similarities in the floristic composition of the levels.

(2) Nová Ves Member (Fig. 1; Table 1 – marked as C, or II.) – this second level comprises
macrofloras from drill cores HV 3, HV 4 (29.1–34.4 m), HV 6, HV 7, V 51–V 67, and pollen
data from drill cores HV 2 (25.6–19.5 m) and HV 3, and the Vonšov and Nová Ves clay pits
(samples B1–B4). The uppermost parts of the drill cores HV 2 and HV 3 contain pollen
samples showing higher abundances of Taxodioideae/Cupressaceae, *Corylus*, Leguminosae, *Myrica*, and Rhamnaceae, and are comparable to the "level I." of the Nero Clay sensu
Stuchlik (1982), i.e., the part "B" of the Nová Ves clay pit.

(3) Nová Ves Member – lignite beds (Fig. 1; Table 1 – marked as D, or III.) –this level includes
macrofloras from the upper part of the drill core HV 4 (22.8–24.3m) and the Nová Ves clay
pit (layers NV 9–10) as well as pollen samples from the Nová Ves clay pit (horizons B5–B9
and C1–C7).

(4) Nová Ves Member – upper part (Fig. 1; Table 1 – marked as E, or IV.) – the macroflora
from layer NV 14 and pollen samples from horizons C9, C<sub>1-4</sub> and D in the Nová Ves clay pit
are included here.

Separately, a composite flora of the Tachov (Cheb–Domažlice) Graben (Fig. 1a; Table 1 –
marked as A) is evaluated in this study, which consists of macrofloras from drill cores V 1 and
V 2, and pollen data from the outcrop at Nová Hospoda (Konzalová in Bůžek et al. 1985).

176

#### 177 **4. Floristic analysis and phytostratigraphic correlation**

The individual palaeofloristic levels within the Vildštejn Formation significantly differ in the 178 179 composition and rate of geoelements (Bůžek et al. 1982, 1985; Table 1; Fig. 2; Appendix 1). 180 The lowermost parts represent the fill of the Tachov (Cheb–Domažlice) Graben, where, besides common remains of Glyptostrobus, also Corylopsis, Symplocos casparyi and 181 182 Microdiptera (incl. Mneme) were recorded in the macrofossil assemblage (palaeofloral 183 assemblage A) stressing affinities with the Early Pliocene (Zanclean, 5.3–3.6 Ma) floras of the Netherland (Brunssumian – Reid and Reid, 1915; Zagwijn, 1959), the Lower Rhine Basin 184 185 (Hambach 9 'Rot-Ton' – Van der Burgh and Zetter, 1998; Wetterau – Mai, 1973), Alsace (Sessenheim 'Saugbagger-Flora' – Geissert et al., 1990; Kvaček et al., 2008; Teodoridis et al., 186 2009), Poland (Krościenko – Szafer, 1947, Mizerna II). In Italy Symplocos casparyi is reported 187 188 up to the Gelasian (about 2 Ma – Martinetto, 2001; Martinetto et al., 2015), and Glyptostrobus certainly still occurs in deposits of late Piacenzian age (ca. 2.8 Ma – Martinetto 189 et al., 2007), and there are possible Gelasian records in central Italy (Martinetto et al., 2014) 190

191 as well as a problematic wood record in the Calabrian (ca. 1.5 Ma – Ravazzi and Van der Burgh, 1994), whereas Corylopsis and Microdiptera have never been recorded there. If a 192 correlation of the Cheb Basin to the Italian palaeofloral sequence was attempted, the 193 194 assemblage A of Vildštein would certainly admit a Piacenzian age (3.6–2.6 Ma), but a 195 Gelasian age could not be excluded. The macrofloras of the Pluto and Nero clays (the Vonšov 196 Member and the lower part of the Nová Ves Member) are richer, including besides 197 Glyptostrobus also other exotic conifers (cf. Taxodium, Chamaecyparis, Pinus cf. spinosa, 198 Picea cf. echinata) and angiosperms (Liriodendron, Ampelopsis, Acer cf. tricuspidatum, 199 Viburnum cf. dilatatum, Weigela, Leucothoë narbonnensis, Epipremnites). The common 200 occurrence of *Quercus roburoides* and *Quercus* cf. *pseudocastanea* stresses close affinities to 201 the Late Pliocene (Reuverian, Piacenzian) floras of Europe, e.g., Frankfurt a. M. (Germany) -202 Mädler (1939); Willershausen (Germany) – Straus (1992), Knobloch (1998); Berga (Germany) 203 Mai and Walther (1988); Auenheim (France) – Kvaček et al. (2008), Teodoridis et al. (2009); 204 Ruszów (Poland) – Hummel (1983, 1991). Also the comparison to the Italian floras points to a Piacenzian age, because there *Taxodium*, *Weigela*, *Leucothoë* and *Epipremnites* are only 205 206 reported up to the late Piacenzian (ca. 2.8 Ma – Martinetto, 1999; Martinetto et al., 2007). 207 According to Bůžek et al. (1985) the rate of exotic elements in the Tachov (Cheb–Domažlice) 208 Graben and Pluto and Nero clays is 30% and 33%, respectively, whereas a transition to the higher levels of the Vildštejn Formation is indicated by a turnover of floristic characteristics. 209 The flora of the lignite beds of the Nová Ves Member differs pronouncedly by the new 210 211 immigration of elements that appear commonly in the European Pleistocene, mainly Picea 212 omoricoides, Pinus cf. sylvestris, boreal Ericaceae (Chamaedaphne, Oxycoccus, Andromeda),

and various herbs, which are typical of central to subarctic Eurasia today (*Scheuchzeria*, *Ranunculus flammula, Menyanthes* cf. *trifoliata*). The poorly documented higher levels of the
mica clay from the upper part of the Nová Ves Member are dominated by the short-needle
Scotch pine typical of boreal Scandinavia, with other Pinaceae, *Juniperus*, dwarf *Salix* and *Alnus.* The rate of exotic elements within the Nová Ves Member decreases to hardly 22% of
the total number of taxa.

219

#### 220 5. Methods

221 Five palaeoenvironmental methods have been applied in this study: Phytosociological

approach, Integrated Plant Record vegetation analysis (IPR-vegetation analysis), Plant

223 Community Scenario approach (PCS approach), Coexistence Approach (CA) and Leaf Margin

Analysis (LMA). The confrontation of these methods allows in our opinion a more precise

evaluation of palaeoenvironmental and palaeoclimatic aspects based on the plant fossil

226 material studied. The method proposed by Bertini and Martinetto (2011) for the

227 construction of palaeovegetation transects, which would have been useful to test the

qualitative transects proposed for the Vildštejn palaeofloras by Bůžek et al. (1985), could not

229 be applied because it requires several localities of the same age in different

230 palaeogeographic contexts.

231

232 **5.1 Phytosociological approach** 

233 The phytosociological approach is a widespread and the earliest vegetation reconstruction method, which is known as an intuitive qualitative approach (e.g., Heer, 1855; Saporta and 234 Marion, 1878; Saporta, 1881; for review see Mai, 1995). Several palaeophytocenological 235 236 markers are usually selected based on their abundance, and their physiognomical and 237 taxonomical characters. On this basis the defined palaeovegetation units (including their 238 nearest living relatives (NLRs) environmental datasets) are correlated to suitable extant 239 vegetation units and/or subunits. Mai (1995, p. 498–603) presents most of the published 240 vegetation types and their synonyms, thus providing a detailed overview of zonal and azonal 241 phytosociological units in current use for the Paleogene and Neogene of Europe (Teodoridis 242 et al. 2011a, pp. 161–162).

243

#### **5.2** Integrated Plant Record vegetation analysis (IPR-vegetation analysis)

245 The IPR-vegetation analysis is a semi-quantitative evaluation technique developed by Kovar-Eder and Kvaček (2003) to map the integrated plant fossil records (leaf, carpological, wood, 246 247 and pollen assemblages) in terms of the zonal vegetation (Kovar-Eder and Kvaček, 2007; 248 Kovar-Eder et al., 2008). Methodologically, the IPR-vegetation analysis uses plant taxonomy, 249 physiognomy, and autoecological characteristics to assign the studied plant record into twelve zonal (9) and azonal (3) taxonomic-physiognomic components: CONIFER (zonal and 250 251 extrazonal conifers), BLD (broad-leaved deciduous woody angiosperms), BLE (broad-leaved 252 evergreen woody angiosperms), SCL (sclerophyllous woody angiosperms), LEG (legume-like 253 woody angiosperms), ZONPALM (zonal palms), ARBFERN (zonal arborescent ferns), DRY

- 254 HERB (open woodland and grassland elements), MESO HERB (mesophytic forest
- undergrowth), AZONAL WOODY (azonal woody trees and shrubs), AZNW (azonal non-woody
- 256 elements) and AQUATIC (aquatic elements). A last component of PROBLEMATIC taxa
- 257 includes unassigned taxa. The relative abundances of the various components of zonal
- 258 woody angiosperms and zonal herb component (MESO HERB + DRY HERB) of zonal woody
- components are calculated as follows in Eqs 1 to 5.
- 260 Eq. 1: % <sub>BLD</sub> =  $BLD/(\sum(BLD, BLE, SCL, LEG, ZONPALM)) \times 100$ ,
- 261 Eq. 2: % <sub>BLE</sub> =  $BLE/(\sum(BLD, BLE, SCL, LEG, ZONPALM)) \times 100$ ,
- 262 Eq. 3: %  $_{SCL+LEG} = SCL+LEG /(\Sigma(BLD, BLE, SCL, LEG, ZONPALM)) \times 100,$
- 263 Eq. 4: % <sub>CONIFER</sub> = CONIFER /( $\Sigma(BLD, BLE, SCL, LEG, ZONPALM, CONIFER, MESO HERB, DRY HERB)$ ) 264 × 100.
- 265 Eq. 5: % <sub>DRY HERB + MESO HERB</sub> = DRY HERB+MESO HERB
- 266  $/(\Sigma(BLD, BLE, SCL, LEG, ZONPALM, CONIFER, MESO HERB, DRY HERB)) \times 100.$
- 267 These values (Eqs 1 to 5) have been defined as distinguishing 8 zonal vegetation types
- including their ecotones (Kovar-Eder and Kvaček, 2007; Teodoridis et al., 2011a): 1)
- temperate to warm-temperate broad-leaved deciduous forests (BLDF); 2) warm-temperate
- 270 to subtropical mixed mesophytic forests (MMF); 3) subtropical broad-leaved evergreen
- forests (BLEF); 4) subtropical, subhumid sclerophyllous or microphyllous forests (ShSF); 5)
- ecotone vegetation of BLDF/MMF; 6) ecotone vegetation of BLEF/MMF; 7) xeric open
- 273 woodlands (OW); and 8) xeric grasslands or steppe (= Xeric grassland). Thresholds for

vegetation types 1 to 4 were validated on living assemblages from China and Japan
considering also the definition of the transitional vegetation (Teodoridis et al., 2011b). A new
IPR-vegetation database was built to organise and summarise the existing fossil and modern
results (Teodoridis et al., 2011a; for details see <u>www.iprdatabase.eu</u>). Recently, Teodoridis et
al. (2012) also tested the IPR vegetation analysis on Palaeogene European floras and modern
tropical vegetation from China.

Due to the low diversity especially of zonal woody angiosperms in the studied material from the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben, the IPR vegetation analysis is not reliably applicable to many of the assemblages (for less than 12 zonal woody angiosperm taxa – see Table 2). However, the values of coniferous and herbaceous components (CONIFER, DRY HERB, MESO HERB) are still informative in these cases, because they are calculated based on the sum of all zonal taxa (see Eqs 4, 5).

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#### **5.3 Plant Community Scenario approach (PCS approach)**

Leaf, carpological and pollen datasets of the Vildštejn Formation and the Tachov (Cheb-Domažlice) Graben are re-evaluated also by means of a recently proposed standardised approach for quantitative plant assemblage analysis and graphical rendering of floralpalaeofloral data: the "Plant Community Scenario" (PCS) approach (Martinetto and Vassio, 2010; Vassio and Martinetto, 2012). The PCS approach is based on the standardised quantitative analysis of plant assemblages in a given volume of sediment. The quantitative data concerning a sigle category of plant parts (e.g. carpological remains, leaves, pollen and

295 spores) and some related qualitative attributes are then converted and illustrated in a simplified 2D sketch (PCS) which has a similar appearance as a vegetation transect. 296 Qualitative information provided for each taxon is synthesised into the PCS by means of 297 "growth forms" (plant categories, Appendix 2) and by subdividing the profile of the PCS 298 299 transect into different ecological subzones (dry, mesophytic, hygrophilous, aquatic) to better 300 display the ecological preferences of the dominant taxa. The resulting vegetation transect 301 conventionally comprises 50 "plant symbols" proportional to the relative abundance of each 302 plant category in the studied assemblage. The analysis of plant assemblages by means of the 303 PCS approach and the visualisation of vegetation sketches allow the standardised, 304 homogeneous and easy comparison within palaeobotanical datasets (Figs 3, 4 and 5). The 305 PCS approach, so far restricted mainly to carpological assemblages (Martinetto and Vassio, 306 2010; Vassio, 2012; Vassio and Martinetto, 2012), can also be applied to pollen (Martinetto et al., 2012; Vassio, 2012) and leaf assemblages (Vassio, 2012). Yet, initial results in using the 307 308 PCS representation for palaeovegetation reconstruction have been obtained only for fruit 309 and seed assemblages based on the combined study of modern standing vegetation (directly 310 surveyed) in a limited catchment area and the modern carpological assemblages buried by 311 its drainage system (Vassio, 2012; Vassio and Martinetto, 2012; Fig. 6). The aim of this research was to describe the quantitative taphonomical bias between the real standing 312 313 vegetation and the final composition of the carpological assemblages originated from it. The 314 gathered data were used to produce coupled vegetation survey-PCS and deposit-PCS, whose 315 comparison is the key for a better interpretation of a deposit-PCS in a fossil context, in which 316 the corresponding palaeovegetation represents the unknown variable (Vassio, 2012; Vassio

317 and Martinetto, 2012). The pictures of the vegetation provided by modern deposit–PCSs can be assumed as models to be compared with ancient deposit-PCS in order to find the best 318 modern deposit analogues. Then, the coupled information of modern deposit–PCS plus 319 320 modern vegetation-PCS can be used as a key for the interpretation of the PCSs obtained 321 from fossil assemblages. At present, the number and the environmental coverage of modern 322 deposit-PCSs is still not sufficient to always enable the determination of modern models of 323 vegetation for fossil assemblages (Bertolotto et al., 2012; Vassio, 2012; Vassio and 324 Martinetto, 2012).

In the present paper, the first experiment of applying the quantitative PCS approach to three plant part records (carpological remains, leaves, pollen and spores) collected from the same sedimentary layers aims at pointing out, discussing and comparing different information, i.e., the represented source area, a possible taphonomical bias, and peculiarities provided by each palaeobotanical dataset.

330

#### 331 **5.4 Coexistence Approach (CA)**

The five flora lists of the different stratigraphic levels described above and given in Table 1 have been assigned to quantitative climatic analyses with the Coexistence Approach (CA, Mosbrugger and Utescher, 1997; Utescher et al., 2014) for micro- and macrofloras separately to compare local and regional climate signals. Due to the general agreements of both signals, micro and macro data also have been combined to provide a higher resolution of results. Additionally, the CA has been applied to all single pollen floras of the drill core HV

338 2 and Nová Ves clay pit separately (Appendix 1) to assess the climate variability within the studied stratigraphic interval of the Vildštejn Formation. Seven climate parameters have 339 been calculated by the CA: MAT (mean annual temperature), CMMT (mean temperature of 340 341 the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual 342 precipitation), as well as HMP (precipitation of the wettest month), LMP (precipitation of the 343 driest month), and WMP (precipitation of the warmest month). Based on the assumption 344 that the climatic requirements of Neogene plant taxa are similar to those of their nearest living relatives (NLRs), the aim of the CA is to find the climatic ranges in which a maximum 345 346 number of NLRs of a given fossil flora can coexist. Those coexistence intervals (one for each 347 climate parameter) are considered the best description of the palaeoclimatic situation under which the given fossil flora lived (for a detailed discussion and introduction to the method 348 349 see Mosbrugger and Utescher, 1997 and Utescher et al., 2000, 2014). The application of the 350 CA is facilitated by the computer program ClimStat and the database PALAEOFLORA which 351 contains NLRs of more than 7500 Cenozoic plant taxa, together with their climatic requirements (1730 datasets) which are derived from meteorological stations located within 352 353 the distribution areas of the taxa (for details see www.palaeoflora.de). The resolution of the 354 calculated climate data varies with respect to the parameter examined; it is highest for temperature-related parameters where it is usually in the range of 1 to 2 °C; results for 355 356 mean annual precipitation reach an accuracy of 100 to 200 mm (Mosbrugger and Utescher, 357 1997). Typically, the resolution and the reliability of the resulting coexistence intervals 358 increase with the number of taxa included in the analysis, and are relatively high in floras 359 with ten or more taxa for which climate parameters are known.

360 Some authors doubt the reliability of the Coexistence Approach especially for certain environmental conditions like mountainous regions (e.g., Kvaček, 2007; Grimm and Denk, 361 2012). However, methodological proxy-proxy and model-proxy comparisons as well as 362 363 several applications of the CA on Oligocene to Pliocene European floras showed its reliability 364 and good climatic resolution (e.g., Bruch et al., 2007, 2011; Utescher et al., 2011, 2014). 365 Utescher et al. (2014) discuss these controversies and give a detailed overview of the power 366 and limitations of the Coexistence Approach. To get additional independent climate data for 367 comparison and validation, Leaf Margin Analysis (LMA) has been conducted to the material as well. 368

369

#### 370 **5.5 Leaf Margin Analysis (LMA)**

371 Leaf margin analysis is a univariate leaf physiognomic technique based on the empirical 372 positive correlation between mean annual temperature (MAT) and the proportions of taxa with toothed vs. taxa with entire leaf margins (woody dicots) of non-pioneer vegetation 373 374 (Bailey and Sinnott, 1916). Wolfe (1979) devised this method and compiled 34 humid to mesic floras from East Asia, including the reference datasets of Wang (1961), to build a linear 375 376 regression equation to predict temperature – see Eq. 6. Recently, Su et al. (2010) reevaluated original Wolfe's datasets and introduced a new equation (Eq. 7) from humid to 377 378 mesic forests from China. Traiser et al. (2005) present regression equation (Eq. 8), which is 379 based on European datasets containing 1835 reference sites. Sampling errors (SE1) and (SE2) 380 were calculated by Wilf (1997) and Miller et al. (2006) – see Eq. 9 and Eq. 10. For the

assemblages from Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben, the
application of LMA is strongly limited by a low abundance of leaf material in the studied
floras. We therefore experimentally used elements typified by pollen and carpological
remains. In such cases, the tooth and/or entire character of the leaf lamina is estimated
based on the known characters of their nearest living relatives (NLRs) presented in Table 1.
This indirect determination of leaf characters should influence the accuracy of the results
further than estimated in Eq. 9 and 10.

388 Eq. 6: MAT 
$$_{LMA1}$$
 = 30.6 x P + 1.41; (r<sup>2</sup> = 0.98),

389 Eq. 7: MAT 
$$_{LMA 2}$$
 = 27.6 x P + 1.038; (r<sup>2</sup> = 0.79),

390 Eq. 8: MAT  $_{LMA3}$  = 31.4 x P + 0.512; (r<sup>2</sup> = 0.60),

391 where  $r^2$  (coefficient of determination).

392 Eq. 9: SE 
$$1_{MAT} = c \sqrt{((P(1-P))/n)}$$
,

- 393 where c (slope of the MAT vs. leaf margin regression, equals 30.6 here), n (total species
- number), P (proportion of *n* species with entire margin, 0 < P < 1).

395 Eq. 10: SE 2 <sub>MAT</sub> =  $V([1 + \varphi (n-1) P(1-P)] \times (P(1-P))/n)$ ,

where  $\phi = 0.052$  (dispersion factor), P (0 < P < 1) is the percentage of woody dicots with

- 397 entire leaves; and n is the total number of woody dicots.
- 398 To compare results of LMA derived from the above presented equations (Eqs 6 to 8), a value
- of mean absolute deviation (MAD) was calculated as follows (Eq. 11):

400 Eq. 11: MAD=
$$1/n \sum_{i=1}^{n} |x_i - x_i|$$
,

401 where  $x_i$  (data element), x (mean of the dataset).

402

#### 403 6. Palaeoenvironmental reconstruction

404 The three palaeovegetational techniques (Phytosociological approach, IPR-vegetation

analysis and PCS approach) and two palaeoclimatic methods (LMA and CA) have been

406 applied on the studied plant assemblages from the Vildštejn Formation and the Tachov

407 (Cheb–Domažlice) Graben to re-evaluate and quantify the previous vegetation and climatic

408 characteristics presented by Bůžek et al. (1985) and to allow to discuss these data in the light

409 of the newly applied techniques.

410

#### 411 6.1 Vegetation reconstruction

412 6.1.1 Phytosociological approach

413 The older part of the Vildštejn Formation, the Vonšov Member – Pluto Clay (Bůžek et al.,

414 1985, Fig. 4.1), is characterised by an assemblage indicating a mixed coniferous and broad-

415 leaved deciduous forest growing on mesic habitats (e.g., *Pinus, Picea, Larix, Liriodendron,* 

416 *Quercus, Castanea, Taxus, Ilex*). However, the three latter elements documented in the

- 417 carpological record are usually interpreted as wetland plants (e.g., Mai and Walther, 1988).
- 418 This forest probably overlapped with riparian vegetation and swamps dominated by shrubs

419 and herb undergrowth (e.g., Taxodium, Acer, Chamaecyparis, Ranunculus, Ampelopsis, 420 Rubus, Nuphar, Polygonum, Sparganium, Dulichium, Carex, Potentilla, Potamogeton, Najas). The studied pollen spectra of the Pluto Clay of the Vonšov Member, i.e., horizons A 1-3 of 421 the Nová Ves clay pit and the middle part of the drill cores HV 2 and HV 3 sensu Stuchlik 422 423 (1982), generally prove the mixed coniferous and broad-leaved deciduous forest vegetation 424 type and show a predominance of swamp and riparian elements, such as Polypodiaceae, 425 Myrica, Salix, Alnus, and mesophytic elements, e.g., Betula, Carpinus, Corylus, Engelhardia, Symplocos, Juniperus, Keteleeria, Cryptomeria-type, Abies (see Table 1, Fig. 2). Bůžek et al. 426 427 (1985, p. 49) pointed out similar modern vegetation types from the USA and southern 428 Europe. In the USA, the area of Weymounth Pine mixed forests approaches the *Taxodium* 429 alluvial forests (with Nyssa, Acer rubrum, various deciduous oaks) and the Chamaecyparis 430 swamp forests. Wet areas outside forests are covered there with sedges, which include also 431 Dulichium (Knapp, 1965). Similarly, broad-leaved deciduous forests are known from wet soils 432 biotopes of the sub-Mediterranean zone in Europe, characterised by Querco-Carpinetum betuli association, while Pinus peuce builds poor stands occupying higher mountain biotopes 433 434 over 1.500 m alt. (Horvat et al., 1974).

The reconstructed vegetation based on the studied plant fossils from the Tachov (Cheb–
Domažlice) Graben shows close affinity to those reconstructed above for the Pluto Clay.

The studied assemblages of the Nero Clay in the Nová Ves Member show a very similar
vegetation pattern corresponding to those of the Vonšov Member (see Bůžek et al., 1985,
Fig. 4.2). The macrofossil plant material indicates a change in floristic compositions, e.g., the
absence of *Quercus, Castanea, Liriodendron, Larix, Picea* contrary to new occurrences of

*Pinus* cf. *spinosa*, *Corylus*, and new aquatic elements, such as *Proserpinaca*, *Nymphaea*, *Najas*, *Menyanthes*, *Juncus*, *Cyperus*, *Cladium*, *Caldesia*, while the pollen spectra show
almost identical taxa composition with higher abundances of Taxodioideae/Cupressaceae, *Corylus*, Leguminosae, *Myrica*, and Rhamnaceae (see Table 1). A high frequency of the
mentioned aquatic and marsh elements corresponds to fluvial to oxbow lake or periphery of
basin environments within the zonal broad-leaved deciduous forest on their upland
periphery.

448 The vegetation reconstructions of the next stratigraphic level of the Nová Ves Member (lignite beds) studied here are based on the floras of the Nová Ves pit (NV 9–10) and drill 449 450 core HV 4, characterised by Bůžek et al. (1985, Fig. 4.3) as mesotrophic transitional moor 451 with Cyperaceae, Scheuchzeria, Menyanthes associated with Pinus cf. spinosa, overlapped in 452 oligotrophic areas to vegetation dominated by Ericaceae (Andromeda polifolia, 453 Chamaedaphne calyculata, Oxycoccus) and in alluvial parts to forest vegetation 454 characterised by *Picea omoricoides* and *Chamaecyparis* cf. *pisifera*. Bůžek et al. (1985) noted analogous modern vegetation in the cool temperate zones of the northern Atlantic part of 455 the USA, like the Northern broad-leaved and Weymounth Pine forest sensu Knapp, (1965, p. 456 457 85), and Europe; the wet rock habitats with *Picea omorika* in the Drina valley at 800-1000 m 458 alt. (Horvat et al., 1974), or the lowland peat bogs with *Chamaedaphne calyculata* in Finland (Overbeck, 1975). Besides an increase in the abundance of *Pinus sylvestris* type, the pollen 459 spectra of the Nová Ves pit show a strong decrease in diversity. Abundances of herbaceous 460 461 and aquatic plants increase and arboreal riparian elements decrease (Alnus, Salix) indicating a change especially in the azonal vegetation. The stratigraphically youngest plant fossils from 462

the Nová Ves clay pit (NV 14, C9, C<sub>1-4</sub>, D) indicate a spreading of the coniferous forest
vegetation type dominated by pines (*Pinus* cf. *halepensis*, *Pinus* cf. *sylvestris*) in the
association with *Picea omoricoides*, *Abies* sp., and *Juniperus* cf. *communis*. The coniferous
forest probably overlapped with riparian vegetation with *Alnus* cf. *rugosa* and *Salix* and
moor and aquatic vegetation with *Menyanthes* cf. *trifoliata*, *Elatine alsinastrum*, *Andromeda polifolia*, *Artemisia*, Cyperaceae etc. (Bůžek et al., 1985, Fig. 4.4; Table 1). These vegetation
types are comparable to modern vegetation known from the Taiga zone (Bůžek et al., 1985).

470

#### 471 6.1.2 IPR-vegetation analysis results

472 According to the thresholds of key components for vegetation types (see the Eqs 1–5) reestablished by Teodoridis et al. (2011b), possible zonal vegetation assemblages are classified 473 (see Table 2). The number of elements per fossil flora varies from 42 to 126, and Appendix 3 474 475 shows how each element is scored for each stratigraphic level in this study. The results derived from the Vonšov Member (Pluto Clay) show a relatively high abundance of arboreal 476 477 elements, i.e., BLD component (78 and 81%), BLE component (17 and 15%), and conifers (16 478 to 21 %), associated with slightly lowervalues for zonal herbs varying from 32 and 33%. Such compositions of the key components correspond more or less to transitional vegetation of 479 480 BLDF/MMF and BLDF vegetation types (see Teodoridis et al., 2011a, Table 2). The values of the zonal herb component exceed 30 % (the threshold for the BLDF and BLDF/MMF 481 482 vegetation types according to Teodoridis et al., 2011a). Stratigraphically comparable floras from the Tachov (Cheb-Domažlice) Graben show similar results, where the values of the 483

484 coniferous, BLD, BLE and zonal herb components vary from 14 to 28 %, 83 to 87 %, 15 to 10
485 %, and 33 to 27 %, respectively, based on the studied macrofossil and microfossil plant
486 remnants. The characteristics of zonal elements show a close relation to the BLDF vegetation
487 type, however, in the analysis of fossil pollen one of the values for the zonal herb
488 component is higher.

The results of the IPR vegetation analysis calculated for the floras of the Nová Ves Member (Nero Clay) show a distinct increase in the abundances of SCL + LEG component (8%) and zonal herbs (35 to 39%), but values for coniferous, BLD and BLE components are almost identical with those from the older levels of the Vildštejn Formation and the Tachov (Cheb– Domažlice) Graben. This specific composition can be described in two ways, as BLDF and/or transitional vegetation of BLDF/MMF vegetation types.

495 The next two stratigraphic levels of the Nová Ves Member, the lignite beds and the upper 496 part, are characterised by a distinct increase in the relative abundance of the zonal herb 497 component, generally exceeding 40 % (max. 50 %, Table 2). These herbaceous elements are 498 associated with taxa of the SCL + LEG component, which are represented in relatively high numbers varying from 7 to 11 %, and with BLD and BLE elements in slightly lower quantities 499 (73 to 83 % and 7 to 11 %). Abundances of the coniferous component vary from 16 to 39 % 500 501 of the zonal elements. The assignment of the studied floras from lignite beds of the Nová 502 Ves Member to vegetation types is equivocal and may correspond to three possible types 503 that are Xeric grasslands or steppe, transitional vegetation of BLDF/MMF and/or vegetation 504 of MMF. The studied floras from the upper part of the Nová Ves Member were excluded from the analysis due to the low number of zonal angiosperms elements (Table 2). 505

Generally, the results of the IPR vegetation analysis indicate several important trends of
vegetation changes during the Late Pliocene to Early Pleistocene period (Table 2, Fig. 7): a)
increase of the DRY herb component within the general increase of zonal herbaceous
elements, b) increase of the SCL + LEG component, and c) decrease of the BLE component.

510

#### 511 6.1.3 PCS approach results

512 Taxa lists provided by different palaeobotanical records (pollen, leaf and carpological, see Appendix 4) show numerous discrepancies in terms of taxonomical resolution, taxa richness, 513 514 and quantitative representation of the same taxon. Almost all pollen taxa have been 515 determined at genus or family level, whilst leaf and carpological taxa provide a more detailed taxonomical identification (most of them are listed at species or genus level). The 516 pollen record has been described as constituted by 100 taxa belonging to 61 families (ferns 517 518 excluded; 35 taxa at genus level); the leaf record consists of 23 taxa attributed to 9 families (ferns excluded); within the seed and fruit record 65 taxa and 37 families have been 519 520 described.

The application of the PCS approach to the fossil assemblages of the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben provided separate graphical sketches for each of the three studied plant organs (pollen, leaves, fruits and seeds), as shown in Fig. 3 for the assemblages of the Nová Ves Member (Nero Clay, assemblage B). The discrepancies between these three PCSs show very well how differently the signal of ancient vegetation is recorded by different types of plant parts.

527 The pollen and leaf PCSs (Figs 3 and 5) are very similar within all the layers analysed and depict a mesic forest variously dominated by conifers. The pollen records also yield some 528 information from the wetland areas, which is not recorded in the leaf flora at all but seems 529 to be predominantly represented by the fruit and seed record (Figs 3 and 4). Most probably 530 531 none of these different records provides an accurate picture of the palaeovegetation, but 532 the integration of information from the three sources (pollen, leaves and fruits/seeds) can 533 lead us to a more sound interpretation with respect to the qualitative reconstructions by Bůžek et al. (1985). However, only for the fruit and seed record modern datasets are 534 available permitting a comparison and interpretation of PCSs in terms of palaeovegetation. 535 536 The four graphical sketches based on carpological data (Figs 3and 4) show a very poor 537 arboreal cover. Most of the transect is occupied by herbaceous freshwater macrophytes and 538 hygrophilous plants, which have been found to be overrepresented in analogous modern 539 situations (Vassio, 2012). Probably the sedimentological setting of the Vildštejn Formation 540 did not allow a broad-scale representation of vegetation in the fruit and seed assemblages (Appendix 4) due to the lack of concentrated carpodeposits (sensu Gee et al., 2005). The 541 542 absence of carpological remains of some taxa occurring in the leaf record (Castanea, Acer, 543 Pinaceae, Quercus and other Fagaceae) can be explained by the large dimensions of their diaspores and partly by the sampling techniques (the possibility to detect a large sized seed 544 545 or fruit is limited in core samples). Moreover, if these plants grew in environments which 546 were not in the direct vicinity of the sedimentary basin, the rather large size of their fruits/seeds would have hampered the transport to the deposition site because of the 547 548 probable absence of strong currents.

549 The Vildštejn fruit and seed-PCSs have been compared to all of the modern carpological deposit-PCSs so-far obtained by analysing different types of modern vegetation and 550 environmental situations in Northern Italy (Vassio, 2012; Vassio and Martinetto, 2012), in 551 552 order to interpret the original source vegetation context. The PCS with the most similar 553 structure to the Vildštejn PCSs was provided by a modern fruit and seed assemblage of the 554 locality named "Orco 1" (small oxbow lake along the Orco river, San Benigno Canavese, NW 555 Italy, 15 km apart from the Alps fringe; Fig. 6). The Orco 1 deposit-PCS (Fig. 6.3) derives from 556 the study of a carpological assemblage formed in a small pond (20 m in diameter), which was 557 associated to a scarcely extended wetland area, largely surrounded by mesic woodland 558 vegetation (Figs 6.1 and 6.2). The similarity of the Orco 1 deposit-PCS to the Vildštejn PCSs 559 (Figs 3 and 4) implies that the Vildštejn fossil assemblages could have been formed in a 560 vegetation context similar to Orco 1. However, this is only one possibility, because it can be assumed that an "Orco 1-type" of PCS may as well occur in a different context, for example a 561 562 wide wetland with far-growing mesic vegetation (no modern PCSs are presently available for this situation). In addition, several modern studies of seed and fruit assemblages in lakes and 563 564 mires (e.g., Birks, 1973; Collinson, 1983; Dieffenbacher-Krall and Halteman, 2000) agreed in 565 indicating the generalised occurrence of a very local vegetation record, with a poor to absent documentation of the regional vegetation. Thus, the PCS analysis of the Vildštejn carpofloras 566 567 would suggest a detailed but very local picture of the fossil flora and vegetation.

The pollen PCSs (Figs 3 and 5) show in all cases more diversified transects with a dominant and varied woody component. It should be emphasised that these PCSs are based on the same qualitative and quantitative data which are commonly used for the interpretation of

571 palaeovegetation on the basis of pollen diagrams, and partly for this reason they show 572 several similarities to the qualitative reconstructions given by Bůžek et al. (1985).

573

#### 574 6.2 Palaeoclimatic signals

#### 575 6.2.1 Coexistence Approach (CA) results

Results of the Coexistence Approach (CA) analysis of macro and micro floral assemblages for 576 the studied stratigraphic levels give narrow coexistence intervals for samples from the 577 Vonšov Member (Figs 8 and 9; Tables 3 and 4). Results from the upper part of the Nová Ves 578 579 Member are clearly less precise due to the lower number of taxa considered especially for 580 data based on pollen. Generally, results from samples of pollen and macro flora are in very good agreement and CA analysis of single pollen samples from the Pluto Clay (the Vonšov 581 Member) and the Nero Clay (the Nová Ves Member) of the drill core HV 2 and Nová Ves clay 582 583 pit have provided very similar numerical results (Tables 3 and 4). The fact that they show no obvious temporal change documents relatively stable palaeoclimatic conditions during the 584 585 time of the Vonšov and the early Nová Ves Member depositional setting. The quantitative results show temperature values considerably higher than present for 586 587 Tachov (Cheb–Domažlice) Graben, Pluto Clay (Vonšov Member) and Nero Clay (the lower part of Nová Ves Member) with mean annual temperatures (MAT) of about 15 °C, winter 588 589 temperatures (CMMT) around 5 °C and summer temperatures (WMMT) of about 25 °C (Fig. 590 8, Tables 3 and 4). In fact, these values are very similar to the ones obtained from the Early 591 Miocene Cypris Formation (Table 4). However, samples from higher levels of Nová Ves

592 Member (lignite beds and upper part) provide data that are close to the present day situation with MAT of 7 °C and CMMT of about -3 °C. Only summer temperatures (WMMT) 593 remain higher than the present day value of 16 °C (meteorological station of Cheb, Table 3, 594 Fig. 8). Moreover, results of this parameter consist of two coexistence intervals which 595 596 indicate either a transitional phase of climate change with vegetation units that are not in 597 equilibrium or represent a mixture of climate signals. The latter could be explained either by 598 a mixture of plant fossils originating from different contemporary vegetation zones or by a 599 mixture of fossils from subsequent climatic settings. The latter, a mixture of different 600 climatic signals, appears to be more likely at the beginning of the Pleistocene with its 601 increasing climate cyclicity. Here, only high-resolution sampling and clear stratigraphic 602 control may be able to give data of higher precision.

603 Similar to temperature parameters, the precipitation values show annual precipitation

604 higher than present in the older parts of the Cheb Basin (the Tachov /Cheb-

Domažlice/Graben, Pluto and Nero clays) with 800–1000 mm, and close to the present day

values in the upper part of the Nová Ves Member (lignite beds and upper part) with 641–766

607 mm and 422–766 mm, respectively (Fig. 9, Table 3). Also precipitations of the wettest month

608 (HMP) and of the warmest month (WMP) decrease in time, whereas the precipitation of the

driest month (LMP) does not reflect significant changes. In general, precipitation data from

610 the Cheb Basin show a development towards modern conditions.

611

## 612 6.2.2 Leaf Margin Analysis (LMA) results

613 Proxy data derived from LMA based on the studied floras/stratigraphic levels of the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben are given in Table 5. The obtained 614 estimates for MAT show generally balanced values for the studied floras, which are 615 independent of the used regression equations, coefficient of determination  $(r^2)$  and/or 616 617 modern calibration datasets (Europe vs. SE Asia), see Eqs 6 to 8. This fact is proved by low 618 values of MAD not exceeding 0.5 °C. With regard to the stratigraphic context, no significant 619 trend is becoming evident during the Vildštejn Formation setting (from Pluto Clay to the 620 mica sandy deposit of Nová Ves). Generally, the LMA data vary from 7.5 to 11.6 °C and show significantly lower values of MAT than those from CA (see Tables 3, 5 and 6). Only the MAT 621 estimated for the upper part of the Nová Ves Member shows a comparable value to the CA 622 data. 623

624

#### 625 7. Discussion

#### 626 7.1 Vegetation cover

The plant spectrum of the Vonšov Member (Pluto Clay) shows relatively high abundances of the broad-leaved deciduous (BLD) component compared to relatively low amounts of the sclerophyllous (SCL+LEG) component. The general character of the zonal vegetation type should be interpreted as an ecotonal vegetation of mixed mesophytic forest and broadleaved deciduous forest (MMF/BLDF) and/or a BLDF vegetation type for the basal Pluto Clay and for the Tachov (Cheb–Domažlice) Graben. The results are strongly affected by low numbers of zonal woody angiosperms (i.e., 6 and 9, Table 2), which limit the reliability of the 634 method. However, the values for the conifer and herbaceous components are accepted in these cases, because their calculation is based on the total number of zonal elements (only 635 results derived from the macrofossil plant material of the Tachov (Cheb–Domažlice) Graben 636 637 and the Nová Ves Member had to be excluded). The relatively high abundances of zonal 638 herbs (over 30%) make a linking to an appropriate zonal vegetation type very problematic. 639 Kovar-Eder et al. (2008, Table 4) defined this threshold for the BLDF type as mostly  $\leq$  30%. 640 Yet, studied living vegetation assemblages of BLDF and MMF from Japan and China show 641 distinctly higher values of this component exceeding 30 %, e.g., assemblages of the BLDF 642 from Shirakami Sanchi (Japan) contain 39, 47 and 53 % of zonal herbs; those from the Meili 643 Snow Mts. (China) comprise 63 and 58 % (Teodoridis et al., 2011b, Table 7). According to the results of the IPR vegetation analyses on modern vegetation from China and Japan, 644 645 Teodoridis et al. (2011b) reveal a distinct underrepresentation of zonal herbs in the fossil record, regardless of whether dealing with leaf, pollen, or fruit assemblages. This fact can be 646 647 applied on the studied floras of the Vonšov Member (Pluto Clay), the Tachov (Cheb-Domažlice) Graben as well as on the floras of the Nová Ves Member (Nero Clay), see Table 2. 648 649 Therefore the unequivocal results of the IPR vegetation analysis and the classifications to 650 BLDF and BLDF/MMF types can be accepted. These predicted vegetation types for the Vonšov Member (Pluto Clay) and the Tachov (Cheb–Domažlice) Graben correspond to the 651 652 syntaxomomical results previously published by Bůžek et al. (1985) as vegetation types of 653 mesic mixed coniferous and broad-leaved deciduous forest (see chapter 6.1.1). The value of zonal conifers detected by the IPR vegetation analysis (15 to 28 %) proved the important role 654 655 of the coniferous elements within the BLDF and/or transitional vegetation of BLDF/MMF.

656 Generally, the IPR-vegetation analysis results of the Nová Ves Member (Nero Clay and lignite beds) show a significant increase of abundance of the SCL + LEG component in account of 657 the BLD component. Besides, the high number of dry herbaceous elements from this 658 stratigraphic level can evocate changes in the composition and structure of the vegetation 659 660 cover. This change can be interpreted as a transition from dense canopy vegetation of BLDF 661 or BLDF/MMF to "more open" light forests of the BLDF or MMF types in areas of zonal to 662 extrazonal uplands. The high abundance of herbaceous component exceeding 44 % indicates 663 a close relation to the vegetation type of Xeric grasslands or steppe (Kovar-Eder et al. 2008, Table 4). Kovar-Eder et al. (2008) distinguished this vegetation type by three late Miocene 664 665 floras from Russia (Sal-Manytsh watershed, drill cores near Sinjavka and Puchljakovskij farmstead). However, only the pollen flora of Puchljakovskij farmstead shows a similar 666 667 composition of the other key components to the floras of the Nová Ves Member (Puchljakovskij farmstead: BLD 77 %, BLE 7 %, SCL+LEG 16 %, DRY HERB 24 % and MESO 668 HERB 19 %). It is evident that Xeric grasslands or steppe show higher values of DRY HERB 669 elements than our results from the Nová Ves Member, therefore this type of vegetation can 670 671 be excluded as a zonal model of vegetation for our studied assemblages. This fact is 672 supported also by a high proportion of arboreal pollen in the Nová Ves Member (Fig. 2), as well as the above mentioned high proportion of the BLD component (73 to 83 %, Table 2, 673 674 Fig. 7). Similarly, the qualitative analysis carried out by Bůžek et al. (1985) considered the 675 mixed coniferous and broad-leaved deciduous forest type for the Nová Ves Member having 676 been replaced by coniferous forest (Pinus, Picea, Juniperus, Abies) during the sedimentation 677 of the upper part of the Nová Ves Member setting. Relevant azonal vegetation types show a

678 wetland to lowland swamp character dominated by shrub and herbaceous elements of Ericaceae, Cyperaceae, and Poaceae that is passing into moor and aquatic environments. 679 Those are well depicted by PCS results based on carpological datasets, preferentially 680 681 recording such environments. In summary, the balanced values of CONIFER, BLD, BLE 682 components and the increase of zonal herbs can corroborate the existence of zonal forest 683 vegetation throughout the Vildštejn Formation setting. The distinct increase of abundances 684 of SCL + LEG and DRY HERB components from 4.5 to 10.6 % and 11 to 17 % (average values) within the Vildštein Formation should evocate a structural change from dense vegetation to 685 more open light forests rather than the transition to a steppe environment. This 686 687 interpretation is supported also by the palaeoclimatic data which records a temperature change from clearly above to close to modern values (Fig. 8, Table 3) excluding harsh 688 689 climatic conditions and a consequential vegetation collapse caused by glacial events. 690 The IPR vegetation analysis has not been widely applied to Pliocene floras yet. Besides the study of Kovar-Eder et al. (2006, 2008) of slightly older, i.e., latest Miocene, plant 691 692 assemblages from Southern Europe, only Teodoridis et al. (2009) published results from the 693 Auenheim-Sessenheim floristic complex covering a similar stratigraphic age as the floras from the Cheb Basin. The carpological flora of Sessenheim "Saugbagger-Flora" and the 694 695 composite flora of Auenheim (based on leaves and carpology) provide abundances of the key components of BLD, BLE, SCL+LEG and zonal herb components of 76.4 %, 20.3 %, 3.3 % 696 and 13.5 %, which indicate the MMF vegetation type for Sessenheim (Teodoridis et al., 697 698 2009). Following the updated classification of IPR vegetation analysis sensu Teodoridis et al. 699 (2011a) such values correspond to ecotone vegetation of BLDF/MMF. The younger flora of

700 Auenheim is characterised by a predominance of BLD components (89 %) contrary to rare 701 evidence of BLE, SCL+LEG, and zonal herb (4%, 7%, and 1.6%), which fits to the BLDF 702 vegetation type. On the other hand, a relatively higher percentage of zonal conifers (16.39 % 703 of zonal elements) represented by mainly boreal elements, such as *Picea* and *Abies* (typical 704 of the mixed coniferous and broad-leaved deciduous forests) can be interpreted as a 705 characteristic feature of most Late Pliocene floras of Europe (Teodoridis et al., 2009) and 706 floristically corresponds to the studied floras of the Nová Ves Member (lignite beds and 707 upper part – see chapter 6.1.1, Bůžek et al., 1985). 708 The PCSs (Figs 3, 4 and 5) do not show the structure of ecotonal vegetation of mixed 709 mesophytic forest and broad-leaved deciduous forest (BLDF/MMF) because the PCSs do not 710 represent actual reconstructions of the zonal ???? palaeovegetation, in contrast to the IPR-

vegetation analysis. Only the pollen PCSs could better represent the original

palaeovegetation structure (Figs 3 and 5), but even in this case the well-known

overrepresentation of saccate pollen (as well as other biases) provides an inconsistent shift

in the appearance of the transect towards a conifer dominated woodland. The fruit and seed

PCSs, based on the Orco 1 modern analogue (Fig. 6), seem to reflect rather accurately the

wetland and aquatic plant communities. Those appear to be very similar to the modern ones

of central Europe, yet with the occurrence of a few exotic plants (*Decodon, Dulichium*,

718 *Proserpinaca*) at least in the assemblages presented on Fig. 6. Conversely, in the youngest

vegetation assemblage of the Nová Ves Member – upper part (Nová Ves pit NV 14 – Fig. 5D)

such exotic elements play no role in the vegetation, whereas the appearance of *Scheuchzeria* 

*palustris,* in association with *Carex nigra,* points to the establishment of a cold-temperate (or

boreal if you prefer- it's the same) peat bog community (*Scheuchzerio-Caricetea fuscae*) in
the basin.

724

#### 725 7.2 Climate signals

726 The climatic datasets derived by the CA analysis of the Cheb Basin floras document a general 727 decrease of temperature and precipitation parameters from the older floras of Tachov 728 (Cheb–Domažlice) Graben, Vonšov Member (Pluto Clay), and the lower part of Nová Ves 729 Member (Nero Clay) towards the younger floras from the upper part of the Nová Ves 730 Member (lignite beds and upper part). However, LMA datasets are close to the modern MAT 731 value and do not show such a cooling trend but relatively stable climatic conditions with 732 values lower than the CA results for the oldest studied floras and higher than those of CA for 733 the youngest floras (Nová Ves Member – upper part). This discrepancy in the results of both 734 methods is due to the relatively low number of entire margined taxa (23 to 33%) and could 735 be caused by the nonstandard application of the LMA technique (using non-leaf material). 736 However, the low abundances of entire elements may be also influenced by others than 737 climatic factors. Elements with dentate leaves frequently occupy riparian vegetation units 738 (wetlands in general) rather than mesophytic zonal uplands plant assemblages and therefore 739 can lead to colder estimates for riparian vegetation assemblages by physiognomic techniques (LMA and Climate Leaf Analysis Multivariate Program – CLAMP) contrary to 740 741 Nearest Living Relative approaches (e.g., Teodoridis, 2004). In fact, this seems to be the case

for the lower LMA temperatures of the Vildštejn Formation and the Tachov (Cheb–
Domažlice) Graben compared to CA results.

744 Few Plio/Pleistocene palaeobotanical sites are reported from Central Europe which were studied for climatic quantifications and could serve for comparison (see Fig. 10). Some of 745 746 those floras have very poor age control and are assigned to Early or Late Pliocene by floristic comparison, although some lack even such information, e.g. the Frankfurt 'Klärbeckenflora' 747 (Mädler, 1939; Krutzsch, 1988). Based on CA analysis Uhl et al. (2007) give MAT data of 14.4 748 749 to 15.5 °C for this flora. Floras dated to Early Pliocene (with radiometric ages from 4.55 to 750 4.2 Ma) are Gérce and Pula in Hungary. Those were analysed by Erdei et al. (2007) with 751 values for Gérce of 15.6–15.7 °C (MAT), 5.0–5.0 °C (CMMT), 24.7–24.8 °C (WMMT), 843– 1160 mm (MAP) and for Pula of 10.0–15.7 °C (MAT), 0.2–4.8 °C (CMMT), 24.7–24.8 °C 752 753 (WMMT), 619–1160 mm (MAP). Uhl et al. (2007) published MAT data derived by various 754 methods for the floras of Berga/Turingia and Willershausen. Mai and Walther (1988) as well 755 as Krutzsch (1988) correlated both floras with the Reuverian (Piacenzian, Late Pliocene). Climate values for Berga/Turingia based on CA range from 13.3 to 16.6 °C (MAT), and from 756 12.5 to 16.5 °C for the locality Willershausen. All those values are very similar to the results 757 of the studied floras from the Tachov (Cheb–Domažlice) Graben, Vonšov Member and the 758 759 lower parts of the Nová Ves Member confirming climatic conditions during the Pliocene of 760 Central Europe, which were generally warmer and more humid than at present. Floristically, the flora of the Tachov (Cheb–Domažlice) Graben seems to be comparable with the French 761 762 'Saugbagger-Flora' whereas the floras of the Pluto and Nero Clays show closer links to the 763 Auenheim assemblage, stratigraphically assigned to Brunssumian (Zanclean, Early Pliocene)

764 and Reuverian (Piacenzian, Late Pliocene), respectively. While our datasets do not show any significant differences between the results from the oldest flora of the Tachov (Cheb-765 766 Domažlice) Graben to the slightly younger Pluto and Nero Clays, datasets from Alsace 767 presented by Teodoridis et al. (2009) potentially suggest a slight decrease of MAT and CMMT from the stratigraphically older 'Saugbagger-Flora' (MAT: 15.3–15.6 °C; CMMT: 2.7 °C; 768 769 WMMT: 23.6–25.1°C; MAP: 979–1146 mm) to the Auenheim assemblage (MAT: 13.6–15.6 770 °C; CMMT: 0.9–1.7 °C; WMMT: 23.6–24.2°C; MAP: 979–1122 mm). Such differences might 771 be explained by a spatial (longitudinal) differentiation of climate with warmer values further 772 eastward and an earlier onset of Late Pliocene cooling in the western part of Central Europe. 773 However, asynchrony of the floras seems to be more probable, especially when considering 774 the poor age constraints of the floras on one hand and a probable forcing also of Pliocene 775 climate and vegetation by eccentricity cycles on the other, as suggested by Popescu et al. 776 (2006) for the Dacic Basin in Romania during 4.9 to 4.3 Ma. 777 Further quantitative climate data are available from the Lower Rhine Basin in NW Germany. 778 For the Rotton Formation (Early Pliocene) CA analyses give values for MAT of 13.3 to 13.8 °C, for CMMT -0.1 to 4.1 °C, and for WMMT 21.1 to 26.4 °C (Hambach Rotton leaf flora -779 Utescher et al., 2000) and 14.1 to 14.4 °C (MAT), 1.8 to 2.7 °C (CMMT), 24.7 to 25.7 °C 780

781 (Hambach Rotton carpo flora – Mosbrugger and Utescher, 1997). Floras from the Reuver

782 Clay (carpoflora, Late Pliocene, method CA – Mosbrugger and Utescher, 1997) provide

values of 13.8 to 13.9 °C (MAT) and 3.4 to 4.6 °C (CMMT) 24.7 to 24.8 °C (WWT), whereas

floras from the Lower Pleistocene part of the succession give considerably lower values of

785 10.6 to 12.4 °C (MAT), -2.8 to 1.3 °C (CMMT), and 21.7 to 23.8 °C (WMMT) (Tegelen

786 carpoflora, Tiglian C – MN17 /Gelasian/, method CA – Mosbrugger et al., 2005). Those latter values correspond well to our datasets from the upper part of the Nová Ves Member (lignite 787 beds and upper part). Temperature parameters from the older floras of the Cheb Basin 788 (Tachov /Cheb–Domažlice/ Graben, Pluto and Nero Clays) are clearly warmer than those 789 790 from the Lower Rhine Basin, which are more similar to the data from Auenheim discussed 791 above. This might indicate a latitudinal gradient of temperatures. Nevertheless, the general 792 temporal development of temperatures with a clear cooling at the beginning of the 793 Pleistocene in the Northern Rhine Basin (Mosbrugger et al., 2005) as well as in the global 794 marine climate record (Zachos et al., 2001) seem to correlate with the results from the Cheb 795 Basin (see Table 6, Fig. 10). However, precipitation data from the Lower Rhine Basin do not 796 show any trend but stay around 1000 mm for the whole sequence. Values for the Rotton 797 Formation (Early Pliocene) are MAP 897–1151 mm, LMP 42–49 mm, HMP 109–170 mm, 798 WMP 47–53 mm (Hambach Rotton leaf flora, method CA – Utescher, et al. 2000) and MAP 799 979–1034 mm, LMP 42–43, HMP 124–139 mm, WMP 84–91 mm (Hambach Rotton 800 carpoflora, method CA – Mosbrugger and Utescher, 1997). Floras from the Reuver Clay give 801 very similar results of MAP 979–1076 mm, LMP 33–49 mm, HMP 115–127 mm, WMP 81–92 802 mm (carpoflora – Mosbrugger and Utescher, 1997). From the Lower Pleistocene level only MAP values are published with 1036-1080 mm (Tegelen carpoflora, Tiglian C – MN17, 803 804 method CA – Mosbrugger et al., 2005).

Such regional differences of the temporal development in precipitation may well be due to the increasing continental character of climate in the eastern parts of Central Europe in pace with the Northern Hemisphere Glaciation (e.g., Sarnthein et al., 2009; Bruch et al., 2011).

808 Unfortunately, the lack of reliable age control for the studied sites as well as for parts of the floras available for comparison hinders for the moment a more insightful interpretation of 809 the terrestrial climatic changes at the Pliocene/Pleistocene boundary in Central Europe. 810 811 Especially the increasing influence of orbital cycles on the Pleistocene climate, i.e., the 812 increased climatic forcing by obliquity and precession with the onset of the Early Pleistocene 813 (Lisiecki and Raymo, 2007), needs to be taken into account and requires higher stratigraphic 814 resolution. Such quantitative studies of Early Pleistocene pollen sequences in deed are able 815 to detect temperature and precipitation changes in phase with obliquity driven climate 816 cycles. For Southern Europe warmer and more humid than present day conditions during 817 warm phases and close to present day conditions during cold phases are documented (e.g., Klotz et al., 2006; Fauquette and Bertini, 2003), whereas in Northern Europe during cold 818 819 phases at least winter temperatures seem to be cooler than present (Pross et al., 2000; Pross and Klotz, 2002). 820

821 Nevertheless, our data consistently show temperatures and precipitation higher than today during the Pliocene and close to modern values in the younger levels, most probable at the 822 beginning of the Pleistocene. There is little evidence for much colder than present day 823 824 conditions as implied by Bůžek et al. (1985) by comparing the youngest flora with modern 825 vegetation from the Taiga zone. However, the cold end of the resulting coexistence intervals may reflect such cold conditions which cannot be resolved in greater detail here. Still, as 826 shown also by data from Southern Europe (Klotz et al., 2006; Fauquette and Bertini, 2003) 827 828 temperatures cooler than present seem to be unlikely even during the cold phases of the 829 earliest Pleistocene climatic cycles. This implies a general overestimation of the climatic

forcing behind vegetation changes by such qualitative interpretations like the one of Bůžek
et al. (1985). Or, to take it the other way, vegetation is reacting highly sensitively to
environmental changes that may be only slight climatic shifts or also other factors than
climate and hard to quantify.

834

#### 835 7. Conclusions

836 The following bullet points conclude crucial results of this study:

A new floristic analysis proved the original statement given by Bůžek et al. (1982,
1985) and corroborate a decreasing trend of exotic elements within the studied floras, i.e.
from the older floras of the Tachov (Cheb–Domažlice) Graben related to Early Pliocene floras
of central Europe, towards floras of the Pluto and Nero Clays with estimated ages of Late
Pliocene (Piacenzian), to floras from the lignite beds and upper part of the Nová Ves
Member characterised by a massive immigration of boreal elements.

843 The results of IPR vegetation analysis indicate a vegetation transition from broadleaved deciduous forests (Tachov /Cheb–Domažlice/ Graben) and/or ecotonal vegetation of 844 845 mixed mesophytic forest / broad-leaved deciduous forests of the Pluto Clay (the Vonšov Member) and the Nero Clay (the Nová Ves Member) to "more open" light forests of the 846 broad-leaved deciduous or mixed mesophytic types grown in areas of zonal to extrazonal 847 848 uplands during the Nová Ves Member (lignite and upper beds) setting. This vegetation change is characterised by a distinct increase of abundances of SCL + LEG (11 %) and DRY 849 850 HERB (16 %) components. The high percentage of herbaceous component exceeding 44 % in the Nová Ves Member could indicate a close relation to the vegetation type of the Xeric
grasslands or steppe. However, the relatively low value of DRY HERB component and a high
proportion of arboreal BLD elements safely exclude this type of vegetation.

• The PCS approach displays the diversified information provided by three different palaeobotanical datasets. Studies on modern assemblages suggest that the carpological PCSs from wetland sediments, mainly deposited in low-energy environments, provide information on the local vegetation structure limited to the azonal component of vegetation. Along with the above-mentioned chronological vegetation trend the wetland communities show a slight but significant loss of exotic elements and point to the development of vegetation contexts more similar to present European ones.

861 Palaeoclimatic signals derived from the CA analysis generally show warmer and more 862 humid conditions than present day for the Pliocene levels and comparable values to the present for the youngest (early Pleistocene) level. CA results for the Vonšov Member give 863 864 values about 15 °C for mean annual temperature, winter temperatures around 5 °C, summer temperatures about 25 °C, and an annual precipitation of more than 900 mm. CA-based 865 866 palaeoclimate data for the Nová Ves Member show a decreasing trend in temperatures as 867 well as in precipitation with a mean annual temperature of about 7 °C, winter temperatures well below zero (-3 °C), and summer temperatures of about 16° C in the upper part of the 868 succession. This may indicate the beginning of a cooler phase at the end of the Pliocene 869 870 and/or beginning of Pleistocene in the Bohemian Massif area.

871	There is no evidence for colder than present-day conditions as implied by Bůžek et al. (1985)
872	by comparing the youngest flora with modern vegetation from the Taiga zone. Such a
873	qualitative interpretation seems to overestimate the climatic forcing behind the observed
874	vegetation changes.

875

### 876 Acknowledgements

877	We would like to thank to	R. Stančíkové (Regional	Office Pilsen, Czech H	-Iydrometeorological
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- 878 Institute) and to D. Richterová (Regional Office Karlovy Vary, Czech Hydrometeorological
- 879 Institute) for the access to the meteorological datasets of Cheb. The study was supported by
- the grant projects of GA ČR (Grant Agency of the Czech Republic) No. P210/10/0124 and the
- 881 Ministry of Education, Youth and Sports (scheme MSM 002162085). This is a contribution to
- 882 NECLIME (www.neclime.de) and ROCEEH (<u>www.roceeh.net</u>).

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#### 1099 Caption to tables and figures

1100 Fig. 1a. Location of the studied floras of the Vildštejn Formation and Tachov (Cheb-

1101 Domažlice) Graben (modified after Bůžek et al., 1985).

1102 **Fig. 1b.** Geological sections of selected drill cores and the Nová Ves clay pit. Symbols: A.

1103 Tachov (Cheb–Domažlice) Graben, B (I.) Vonšov Member (Pluto Clay), C (II.) Nová Ves

1104 Member (Nero Clay), D. (III.) Nová Ves Member (lignite beds), and E. (IV.) the Nová Ves

1105 Member (upper part), modified after Bůžek et al. (1985). Stratigraphic data after Bucha et al

1106 (1990) and Špičíková et al. (2000); GPTS dataset modified after Lourens et al. (1996) and

1107 Petronio et al. (2011).

**Fig. 2.** Simplified pollen diagrams of drill core HV 2 (a) and Nová Ves clay pit (b). The relative abundances of trees, shrubs and herbs, as well as the AP/NAP ratio are based on the sum of gymnosperm and angiosperm taxa excluding aquatic and hydrophytes to better reflect the regional vegetation. For all other taxa the total pollen sum served as the base for calculating percentages. For details and full taxa list see Appendix 1.

Fig. 3. Plant Community Scenario diagrams (PCSs) provided by carpological, leaf and pollen
records from the Vildštejn Formation, stratigraphic level/horizon B (Vonšov Member – Pluto
Clay). Notice that the PCSs do not represent actual reconstructions of the
palaeoenvironment and palaeovegetation, rather they are a graphical representation of
quantitative palaeobotanical data. Each typology of plant symbol is referred to a group of
taxa that shares habitus, size and ecological features (Martinetto and Vassio, 2010; Vassio,
2012, Vassio and Martinetto, 2012). Fifty plant symbols and twenty-five taxa names, among

1120 the most frequent floristic elements, have been reported into the diagram by taking into 1121 account their ecological requirement, expressed by the belts in different colour. The breadth 1122 of each belt is proportional to the frequency of plants classified as mesophytic, hygrophilous 1123 or aquatic in the fossil assemblage; also the proportion of different plant symbols reflects 1124 the frequencies of the taxa belonging to each 'growth form' group within the fossil 1125 assemblages (e.g., broad-leaved deciduous shrub short/medium/tall, broad-leaved 1126 deciduous tree short/medium/tall, evergreen conifer tree Pinaceae, aquatic submergent 1127 herb short/medium/tall etc.).

1128 Fig. 4. Plant Community Scenario diagrams provided by carpological records from the

1129 Vildštejn Formation and Tachov (Cheb–Domažlice) Graben. Stratigraphical levels/horizons: A

1130 (Tachov /Cheb–Domažlice/ Graben), C (Nová Ves Member – Nero Clay), D (Nová Ves

1131 Member – lignite beds). For B (Vonšov Member – Pluto Clay), see Fig. 3

1132 Fig. 5. Plant Community Scenario diagrams provided by pollen records from the Vildštejn

1133 Formation. Stratigraphic levels/horizons: C (Nová Ves Member – Nero Clay), D (Nová Ves

Member – lignite beds), E (Nová Ves Member – upper part). For B (Vonšov Member – Pluto
Clay), see Fig. 3.

Fig. 6. Plant Community Scenario diagrams (PCSs) provided by carpological records from the modern locality Orco 1 (San Benigno Canavese, NW Italy). – 1. vegetation-PCS obtained from the standing vegetation survey of the area (diameter length ca. 100 m) ahead of the small pond from where a fruit-bearing sediment sample was analysed. 2. vegetation-PCS obtained from the standing vegetation survey of a small wetland crossed by a brook, extended few

tens of meters ahead of the small pond. 3. deposit-PCS obtained from a modern fruit and
seed assemblage buried in the silty sediments of the pond. The three PCSs clearly show that
this fruit and seed assemblage provides a very local record of the vegetation: the aspect of
the transect is similar to the wetland vegetation close to the pond, and the signal of the
mesophytic woodland which grows just 20 m apart of the pond is not well recorded by the
carpological assemblage.

1147 Fig. 7. General vegetation changes and trends based on the IPR vegetation results of the 1148 studied floras from the Vildštein Formation and Tachov (Cheb–Domažlice) Graben during the 1149 Late Pliocene to Early Pleistocene period. Symbols: % CONIFER (percentages of zonal and 1150 extrazonal conifers), % BLD (percentages of broad-leaved deciduous woody angiosperms), % BLE (percentages of broad-leaved evergreen woody angiosperms), % SCL+LEG (percentages 1151 1152 of sclerophyllous woody and legume-like woody angiosperms), % DRY HERB (percentages of 1153 open woodland and grassland elements), % MESO HERB (percentages of mesophytic forest 1154 undergrowth elements), and % zonal herb (percentages of zonal herbaceous elements, = % 1155 DRY HERB + % MESO HERB). The parameters are calculated based on the equations 1–5. A (Tachov/Cheb–Domažlice/ Graben), B (Vonšov Member – Pluto Clay), C (Nová Ves Member – 1156 1157 Nero Clay), D (Nová Ves Member – lignite beds).

Fig. 8. Palaeoclimatic quantification of temperature parameters based on the Coexistence
Approach, for MAT (mean annual temperature), CMMT (mean temperature of the coldest
month) and WMMT (mean temperature of the warmest month) derived from the
Coexistence Approach (CA). Symbols: A (Tachov/Cheb–Domažlice/ Graben), B (Vonšov
Member – Pluto Clay), C (Nová Ves Member – Nero Clay), D (Nová Ves Member – lignite

beds), E (Nová Ves Member – upper part), green square (based on macrofossil plant
remnants), yellow circle (based on microfossil plant remnants), red rhomb (based on macroand microfossil plant remnants), solid vertical lines (present day climatic data from the
meteorological station of Cheb). For data source see Table 3.

1167 Fig. 9 Palaeoclimatic quantification of temperature parameters based on the Coexistence 1168 Approach, forMAP (mean annual precipitation), HMP (precipitation of the driest month), 1169 LMP (precipitation of the driest month) and WMP (precipitation of the warmest month) 1170 derived from the Coexistence Approach (CA). Symbols: A (Tachov/Cheb–Domažlice/ Graben), 1171 B (Vonšov Member – Pluto Clay), C (Nová Ves Member – Nero Clay), D (Nová Ves Member – 1172 lignite beds), E (Nová Ves Member – upper part), green square (based on macrofossil plant remnants), yellow circle (based on microfossil plant remnants), red rhomb (based on macro-1173 1174 and microfossil plant remnants), solid vertical lines (present day climatic datasets from the 1175 meteorological station of Cheb). For data source see Table 3.

1176 Fig. 10. Comparison of palaeoclimatic proxy data based on the Coexistence Approach (CA) 1177 from the studied floras of the Vildštejn Formation, Tachov (Cheb–Domažlice) Graben and 1178 selected Pliocene and Pleistocene floras of Europe . – Symbols: 1. Tachov (Cheb–Domažlice) Graben, 2. Frankfurt 'Klärbeckenflora' (Germany), 3. Gérce (Hungary), 4. Pula (Hungary), 5. 1179 1180 Berga (Germany), 6. Willershausen (Germany), 7. Sessenheim (France), 8. Hambach Rotton 1181 (Germany) – leaf, 9. Hambach Rotton (Germany) – carpology, 10. Vonšov Beds (Pluto Clay), 1182 11. Nová Ves Beds (Nero Clay), 12. Auenheim (France), 13. Reuver Clay (Germany), 14. Nová 1183 Ves Beds (lignite beds), 15. Nová Ves Beds (upper beds), and 16. Tegelen (the Netherlands).

1185	Table 1. Summary of the floristic compositions of the studied floras of the Vildštejn
1186	Formation and Tachov (Cheb–Domažlice) Graben including suggested Nearest Living
1187	Relatives. Symbols: C (cone), F (fruit), L (leaf), P (pollen), S (seed), Sp (spore) and W (wood)
1188	Table 2. Results of the IPR vegetation analysis from the studied floras of the Vildštejn
1189	Formation and Tachov (Cheb–Domažlice) Graben. Symbols: L (leaf flora), F (fruit and seed
1190	flora), P (pollen flora). Percentages of the BLD (broad-leaved deciduous woody
1191	angiosperms), BLE (broad-leaved evergreen woody angiosperms), SCL+LEG (sclerophyllous
1192	woody and legume-like woody angiosperms), DRY HERB (open woodland and grassland
1193	elements), MESO HERB (mesophytic forest undergrowth elements) components were
1194	calculated following the equations 1 to 4.
1195	Table 3. Results of the palaeoclimatic quantification based on the Coexistence Approach for
1196	the studied floras from the Vildštejn Formation and Tachov (Cheb–Domažlice) Graben
1197	including the limiting taxa of the coexistence intervals. Symbols: L (leaf flora), F (fruit and
1197 1198	including the limiting taxa of the coexistence intervals. Symbols: L (leaf flora), F (fruit and seed flora), P (pollen flora), MAT (mean annual temperature), CMMT (mean temperature of
1197 1198 1199	including the limiting taxa of the coexistence intervals. Symbols: L (leaf flora), F (fruit and seed flora), P (pollen flora), MAT (mean annual temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual
1197 1198 1199 1200	including the limiting taxa of the coexistence intervals. Symbols: L (leaf flora), F (fruit and seed flora), P (pollen flora), MAT (mean annual temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual precipitation), HMP (precipitation of the driest month), LMP (precipitation of the driest
1197 1198 1199 1200 1201	including the limiting taxa of the coexistence intervals. Symbols: L (leaf flora), F (fruit and seed flora), P (pollen flora), MAT (mean annual temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual precipitation), HMP (precipitation of the driest month), LMP (precipitation of the driest month) and WMP (precipitation of the warmest month). The source of climatic parameters
1197 1198 1199 1200 1201 1202	including the limiting taxa of the coexistence intervals. Symbols: L (leaf flora), F (fruit and seed flora), P (pollen flora), MAT (mean annual temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual precipitation), HMP (precipitation of the driest month), LMP (precipitation of the driest month) and WMP (precipitation of the warmest month). The source of climatic parameters from the meteorological station of Cheb is derived from the website of the Czech

Table 4. Results of the palaeoclimatic quantification based on the Coexistence Approach for
the studied fossiliferous horizons of drill core HV 2 and levels of Nová Ves clay pit (the
Vildštejn Formation) based on micro (pollen) plant remains. Symbols: MAT (mean annual
temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature
of the warmest month), MAP (mean annual precipitation), HMP (highest monthly
precipitation) LMP (lowest monthly precipitation) and (WMP) precipitation of the warmest
month.

1211 **Table 5.** Palaeoclimate proxy data of MAT (mean annual temperature) derived from Leaf

1212 Margin Analysis were calculated following the equations 5 to 7 as well as values of sampling

1213 errors (Eqs 8 to 9) and mean absolute deviation (Eq. 10). Symbols: *n* (total species number),

1214 *P* (proportion of *n* species with entire margin, 0 < P < 1).

Appendix 1. Raw data pollen counts of drill core HV 2 and Nová Ves clay pit (Vildštejn
Formation).

Appendix 2. List of acronyms, growth forms and plant symbols used within Plant Community
Scenario (PCS). The symbol size for herbaceous plants are twice as large as they are drawn in
the PCSs in order to make their visualization easier (modified after Vassio and Martinetto,
2012).

Appendix 3. Plant taxa occurring in the studied floras from the Vildštejn Formation and
 Tachov (Cheb–Domažlice) Graben and their scoring according to the IPR-vegetation analysis.

1223 Appendix 4. Quantitative and qualitative datasets of Plant Community Scenario diagrams 1224 (PCSs) referred to floristic lists obtained by leaf, pollen and carpological record analyses 1225 within Vildštejn Formation (Table 1) and by actuopalaeobotanical analysis on carpological 1226 assemblages in modern sediments from NW Italy, Orco 1 (Fig. 6) – details in Vassio (2012). 1227 The datasets comprise also calculation useful in PCS construction on the basis of absolute 1228 quantitative data (column A) transformed into percentages (column X (%)). The percent 1229 values are summed up by grouping taxa a) belonging to the same ecological zone in order to 1230 obtain the X, M, HY and A zone extension within the PCS transects (X – xerophytic, M – mesophytic, HY – hygrophilous, A – aquatic); b) with the same growth form in order to 1231 define how many plant symbols of each type to be drawn in the PCS (see Appendix 2, 1232 1233 modified after Vassio, 2012 and Vassio and Martinetto, 2012). 'Plant organs' column 1234 abbreviations: S (seed), F (fruit), Sp (spore), mC (male cone), Cs (cone scale), L (leaf), P 1235 (pollen).