Plio-Pleistocene floras of the Vildštejn Formation in the Cheb Basin, Czech Republic – a floristic and palaeoenvironmental review

(Article begins on next page)

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

2 **floristic and palaeoenvironmental review**

3 Vasilis Teodoridis [a] [*], Angela A. Bruch [b], Elena Vassio [c], Edoardo Martinetto [c], Zlatko Kvaček [d]

4 and Leon Stuchlik [e]

5 [a] Department of Biology and Environmental Studies, Faculty of Education, Charles University

6 in Prague, Magdalény Rettigové 4, 116 39 Prague 1, Czech Republic, e-mail:

7 vasilis.teodoridis@pedf.cuni.cz

8 [b] Heidelberg Academy of Sciences and Humanities, Research Center 'The Role of Culture in

9 Early Expansions of Humans' at Senckenberg Research Institut, Senckenberganlage 25,

10 60325 Frankfurt am Main, Germany, e-mail: abruch@senckenberg.de

11 [c] Dipartimento di Scienze della Terra, Università degli Studi di Torino, Via Valperga Caluso 35,

12 I-10125 Torino, Italy, e-mail: edoardo.martinetto@unito.it; elena_vassio@yahoo.it

13 [d] Institute of Geology and Palaeontology, Faculty of Sciences, Charles University in Prague,

14 Albertov 6, 128 43 Prague 2, Czech Republic, kvacek@natur.cuni.cz

15 [f] Wladyslaw Szafer Institute of Botany, Polish Academy of Sciences, Lubicz 46, 31-512

16 Cracow, Poland, e-mail: L.Stuchlik@botany.pl

17 *corresponding author

18

19 **Abstract**

20   Fossil plant assemblages (foliage, fruits and seeds, pollen, wood) from the Pliocene and early

21   Pleistocene deposits in W Bohemia (the Vildštejn Formation of the Cheb Basin, Tachov

22   /Cheb–Domažlice/ Graben) are newly analysed using several palaeoenvironmental methods

23   aiming at reconstructing palaeovegetation and palaeoclimatic changes. Floras of four

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

28   uplands. This vegetational change is characterised by an immigration of dry herbaceous and

29   sclerophyllous elements. Wetland communities stepwise loose exotic components and point

30   to cool-temperate conditions similar to the present higher in the profiles. Palaeoclimatic

31   signals show warmer and more humid conditions for the Pliocene levels (about 15°C of mean

32   annual temperature, 5°C of mean winter and 25°C of mean summer temperature, more than

33   900 mm of mean annual precipitation). Early Pleistocene proxy data indicate the beginning

34   of a cooler phase at the Plio-Pleistocene boundary (about 7°C of mean annual temperature

35   and decreasing trend of precipitation), but no colder conditions than the present day in the

36   NW part of the Bohemian Massif.

37

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

42   outcrops of the Vildštejn Formation in the Cheb Basin and the Tachov (Cheb–Domažlice)

43   Graben in western Bohemia were assigned by Bůžek et al. (1985) to the Pliocene-Pleistocene

44   transition, according to the stratigraphic scheme of Gibbard et al. (2010). The fossils have

45   been known since pioneer studies by Karl Rudolph in 1935 and were more systematically

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

48   the plant material described so far (Bůžek et al., 1985; Stuchlik, 1982) is re-evaluated in

49   current taxonomical context (EM, ZK, VT) and results of subsequently analysed new pollen

50   material (Stuchlik, unpublished) are added (AAB, LS). Several palaeoenvironmental

51   techniques are applied on the complete fossil plant spectra from the Vildštejn Formation

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

55   a semi-quantitative method of the Integrated Plant Record vegetation analysis (VT). This

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

58   applied on Plio-Pleistocene floras originated partly under cool-temperate conditions. The

59   obtained results are discussed in the context of those derived from other palaeovegetational

60   techniques allowing to reconstruct complex qualitative and quantitative characteristics of

61   the fossil vegetation, i.e., Phytosociological approach (ZK, VT) and Plant Community Scenario

62   approach (EV, EM). Similarly, the multi-technique approach was used to detect climatic

3

63   changes during the sedimentation of the Vildštejn Formation and the Tachov (Cheb–

64   Domažlice) Graben. The method of the Coexistence Approach (AAB) assesses palaeoclimatic

65   estimates based on the analysis of the micro- and macrofossil plant material. The second

66   palaeoclimatic technique is the physiognomic method of the Leaf Margin Analysis (VT). Its

67   application is strongly limited by the scarcity of the leaf material at the studied sites.

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

70   (NLRs). The obtained climatic datasets and CA results are discussed within the frame of

71   palaeoclimatic data obtained for other Late Pliocene and Early Pleistocene floras of Europe.

72

73   **2. Geological setting**

74   The Cheb Basin, the westernmost lignite basin within the Ohře (Eger) Graben lies on a

75   tectonic crossing of two major structures – the Ohře (Eger) Rift of WSW-ENE direction

76   (Ziegler, 1990) and a younger structure of the Tachov (Cheb–Domažlice) Graben trending in

77   NNW-SSE direction (e.g., Rojík et al., 2010; Fig. 1a). Its sedimentary filling consists of several

78   lithostratigraphic units (formations or levels), partly informally defined, deposited in the

79   time interval from Late Eocene to Pliocene-Pleistocene (e.g., Ambrož, 1958; Václ, 1979;

80   Bůžek, et al. 1982; Bucha et al., 1990; Špičáková et al., 2000; Kvaček and Teodoridis, 2007;

81   Rojík et al., 2010). Besides the formally defined formations of Staré Sedlo (Late Eocene),

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 tectono-

85   sedimentary evaluation of the Cheb Basin and the Tachov (Cheb–Domažlice) Graben

86   focusing on three main depositional units only, i.e., the Lower Clay and Sand and Main Coal

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

91   sediments was deposited after a hiatus lasting for about 12 million years partly on the Early

92   Miocene Cypris Formation or on crystalline and granitic basement near the western border

93   of the basin. The average thickness of the Vildštejn Formation usually varies from 30 to 60

94   m, but the maximal value exceeds 100 m at the Mariánské Lázně fault belonging to the

95   tectonic system of the Tachov (Cheb–Domažlice) Graben. The Vildštejn Formation is divided

96   into two members. The older Vonšov Member is well developed near the villages of Skalná

97   (formerly Vildštejn or Wildstein) and Vonšov (formerly Fonsau) and represents weathered

98   illite green clay (partly reworked Cypris claystone), grey-violet or reddish tough clay (Blauton

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

101   Member represents a relatively heterogeneous sequence of layers with a total thickness of

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

107   the Vonšov Member because this clay deposit is coarser, rich in mica and contains only

108   kaolinite with less ordered structure and lower content of molecular water like clays of the

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

113   represents an independent sedimentary cycle (Fig. 1a, b).

114   The Tachov (Cheb–Domažlice) Graben is partly filled by Neogene deposits which have been

115   interpreted as fluviatile sediments of "the river F" sensu Pešek and Spudil (1986). This river

116   system probably drained the western part of the Czech Republic towards the Cheb Basin

117   during the Pliocene (Pešek and Spudil, 1986; Malkovský, 1995). The studied plant macro- and

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

120   10 m thick clayey sediments with thin lignitic beds and brown clays that interchange with

121   kaolinitic clays and claystones. This fossiliferous part (mainly clayey horizons) is overlain by 5

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).

124   Exact dating of fossiliferous deposits of the Vildštejn Formation and the Tachov (Cheb–

125   Domažlice) Graben is not always available (Fig. 1b). The palaeomagnetic records derived

126   from the drill cores of NK-24 and NK-25 (Nový Kostel) suppose a time range from 4.7 to 1.4

127   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.

129   (2000) present a time range from 4.5 to 1.5 Ma for the deposition of the Vildštejn Formation

130   as a whole.

131

132   **3. Material**

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

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

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

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

137   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

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

140   The study follows the original concept of fossiliferous horizons within the Vildštejn

141   Formation given by Bůžek et al. (1985) and recognizes four stratigraphic levels for

142   quantitative analyses:

143   **(1) Vonšov Member** (Fig. 1; Table 1 – marked as B, or I.) – this level includes macrofossil

144   floras from the drill core HV 9, and pollen data from the lower part of the Nová Ves clay pit

145   (levels A1-A3) and the lower part of drill cores HV 2 and HV 3 (Stuchlik, 1982). Due to the

146   sandy facies in drill cores HV 2 and HV 3 the stratigraphic boundaries between the Vonšov

147   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

150   riparian and wetland elements (*Salix*, *Nyssa*, Cyperaceae, etc.) as well as significant

151   occurrences of *Betula*, *Corylus*, and *Myrica*, and are comparable with part "A" (Pluto Clay) of

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

155   between the Pluto and Nero clays is not given by Stuchlik (1982) and correlation of the

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.

159   **(2) Nová Ves Member** (Fig. 1; Table 1 – marked as C, or II.) – this second level comprises

160   macrofloras from drill cores HV 3, HV 4 (29.1–34.4 m), HV 6, HV 7, V 51–V 67, and pollen

161   data from drill cores HV 2 (25.6–19.5 m) and HV 3, and the Vonšov and Nová Ves clay pits

162   (samples B1–B4). The uppermost parts of the drill cores HV 2 and HV 3 contain pollen

163   samples showing higher abundances of Taxodioideae/Cupressaceae, *Corylus*, Leguminosae,

164   *Myrica*, and Rhamnaceae, and are comparable to the "level I." of the Nero Clay sensu

165   Stuchlik (1982), i.e., the part "B" of the Nová Ves clay pit.

166   **(3) Nová Ves Member – lignite beds** (Fig. 1; Table 1 – marked as D, or III.) –this level includes

167   macrofloras from the upper part of the drill core HV 4 (22.8–24.3m) and the Nová Ves clay

168   pit (layers NV 9–10) as well as pollen samples from the Nová Ves clay pit (horizons B5–B9

169   and C1–C7).

170   **(4) Nová Ves Member – upper part** (Fig. 1; Table 1 – marked as E, or IV.) – the macroflora

171   from layer NV 14 and pollen samples from horizons C9, C_{1-4} and D in the Nová Ves clay pit

172   are included here.

173   Separately, a composite flora of the **Tachov (Cheb–Domažlice) Graben** (Fig. 1a; Table 1 –

174   marked as A) is evaluated in this study, which consists of macrofloras from drill cores V 1 and

175   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**

178   The individual palaeofloristic levels within the Vildštejn Formation significantly differ in the

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,

181   besides common remains of *Glyptostrobus*, also *Corylopsis*, *Symplocos casparyi* and

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

184   Netherland (Brunssumian – Reid and Reid, 1915; Zagwijn, 1959), the Lower Rhine Basin

185   (Hambach 9 'Rot-Ton'– Van der Burgh and Zetter, 1998; Wetterau – Mai, 1973), Alsace

186   (Sessenheim 'Saugbagger-Flora' – Geissert et al., 1990; Kvaček et al., 2008; Teodoridis et al.,

187   2009), Poland (Krościenko – Szafer, 1947, Mizerna II). In Italy *Symplocos casparyi* is reported

188   up to the Gelasian (about 2 Ma – Martinetto, 2001; Martinetto et al., 2015), and

189   *Glyptostrobus* certainly still occurs in deposits of late Piacenzian age (ca. 2.8 Ma – Martinetto

190   et al., 2007), and there are possible Gelasian records in central Italy (Martinetto et al., 2014)

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191   as well as a problematic wood record in the Calabrian (ca. 1.5 Ma – Ravazzi and Van der

192   Burgh, 1994), whereas *Corylopsis* and *Microdiptera* have never been recorded there. If a

193   correlation of the Cheb Basin to the Italian palaeofloral sequence was attempted, the

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

205   Piacenzian age, because there *Taxodium*, *Weigela*, *Leucothoë* and *Epipremnites* are only

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

209   higher levels of the Vildštejn Formation is indicated by a turnover of floristic characteristics.

210   The flora of the lignite beds of the Nová Ves Member differs pronouncedly by the new

211   immigration of elements that appear commonly in the European Pleistocene, mainly *Picea*

212   *omoricoides*, *Pinus* cf. *sylvestris*, boreal Ericaceae (*Chamaedaphne, Oxycoccus, Andromeda*),

213   and various herbs, which are typical of central to subarctic Eurasia today (*Scheuchzeria,*

214   *Ranunculus flammula, Menyanthes* cf. *trifoliata*). The poorly documented higher levels of the

215   mica clay from the upper part of the Nová Ves Member are dominated by the short-needle

216   Scotch pine typical of boreal Scandinavia, with other Pinaceae, *Juniperus,* dwarf *Salix* and

217   *Alnus.* The rate of exotic elements within the Nová Ves Member decreases to hardly 22% of

218   the total number of taxa.

219

220   **5. Methods**

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

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

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

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

225   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

228   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

234   method, which is known as an intuitive qualitative approach (e.g., Heer, 1855; Saporta and

235   Marion, 1878; Saporta, 1881; for review see Mai, 1995). Several palaeophytocenological

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

244   **5.2 Integrated Plant Record vegetation analysis (IPR-vegetation analysis)**

245   The IPR-vegetation analysis is a semi-quantitative evaluation technique developed by Kovar-

246   Eder and Kvaček (2003) to map the integrated plant fossil records (leaf, carpological, wood,

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

250   twelve zonal (9) and azonal (3) taxonomic-physiognomic components: CONIFER (zonal and

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

255   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

259   components are calculated as follows in Eqs 1 to 5.

260   Eq. 1: $\%_{BLD} = BLD/(\sum(BLD,BLE,SCL,LEG,ZONPALM)) \times 100$,

261   Eq. 2: $\%_{BLE} = BLE/(\sum(BLD,BLE,SCL,LEG,ZONPALM)) \times 100$,

262   Eq. 3: $\%_{SCL+LEG} = SCL+LEG /(\sum(BLD,BLE,SCL,LEG,ZONPALM)) \times 100$,

263   Eq. 4: $\%_{CONIFER} = CONIFER /(\sum(BLD,BLE,SCL,LEG,ZONPALM,CONIFER,MESO\ HERB,DRY\ HERB))$

264      $\times 100$.

265   Eq. 5: $\%_{DRY\ HERB + MESO\ HERB} = DRY\ HERB+MESO\ HERB$

266      $/(\sum(BLD,BLE,SCL,LEG,ZONPALM,CONIFER,MESO\ HERB,DRY\ HERB)) \times 100$.

267   These values (Eqs 1 to 5) have been defined as distinguishing 8 zonal vegetation types

268   including their ecotones (Kovar-Eder and Kvaček, 2007; Teodoridis et al., 2011a): 1)

269   temperate to warm-temperate broad-leaved deciduous forests (BLDF); 2) warm-temperate

270   to subtropical mixed mesophytic forests (MMF); 3) subtropical broad-leaved evergreen

271   forests (BLEF); 4) subtropical, subhumid sclerophyllous or microphyllous forests (ShSF); 5)

272   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

274   vegetation types 1 to 4 were validated on living assemblages from China and Japan

275   considering also the definition of the transitional vegetation (Teodoridis et al., 2011b). A new

276   IPR-vegetation database was built to organise and summarise the existing fossil and modern

277   results (Teodoridis et al., 2011a; for details see www.iprdatabase.eu). Recently, Teodoridis et

278   al. (2012) also tested the IPR vegetation analysis on Palaeogene European floras and modern

279   tropical vegetation from China.

280   Due to the low diversity especially of zonal woody angiosperms in the studied material from

281   the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben, the IPR vegetation

282   analysis is not reliably applicable to many of the assemblages (for less than 12 zonal woody

283   angiosperm taxa – see Table 2). However, the values of coniferous and herbaceous

284   components (CONIFER, DRY HERB, MESO HERB) are still informative in these cases, because

285   they are calculated based on the sum of all zonal taxa (see Eqs 4, 5).

286

287   **5.3 Plant Community Scenario approach (PCS approach)**

288   Leaf, carpological and pollen datasets of the Vildštejn Formation and the Tachov (Cheb–

289   Domažlice) Graben are re-evaluated also by means of a recently proposed standardised

290   approach for quantitative plant assemblage analysis and graphical rendering of floral-

291   palaeofloral data: the "Plant Community Scenario" (PCS) approach (Martinetto and Vassio,

292   2010; Vassio and Martinetto, 2012). The PCS approach is based on the standardised

293   quantitative analysis of plant assemblages in a given volume of sediment. The quantitative

294   data concerning a sigle category of plant parts (e.g. carpological remains, leaves, pollen and

14

295 spores) and some related qualitative attributes are then converted and illustrated in a

296 simplified 2D sketch (PCS) which has a similar appearance as a vegetation transect.

297 Qualitative information provided for each taxon is synthesised into the PCS by means of

298 "growth forms" (plant categories, Appendix 2) and by subdividing the profile of the PCS

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

307 et al., 2012; Vassio, 2012) and leaf assemblages (Vassio, 2012). Yet, initial results in using the

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

312 research was to describe the quantitative taphonomical bias between the real standing

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

15

317 and Martinetto, 2012). The pictures of the vegetation provided by modern deposit–PCSs can

318 be assumed as models to be compared with ancient deposit–PCS in order to find the best

319 modern deposit analogues. Then, the coupled information of modern deposit–PCS plus

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).

325 In the present paper, the first experiment of applying the quantitative PCS approach to three

326 plant part records (carpological remains, leaves, pollen and spores) collected from the same

327 sedimentary layers aims at pointing out, discussing and comparing different information, i.e.,

328 the represented source area, a possible taphonomical bias, and peculiarities provided by

329 each palaeobotanical dataset.

330

331 **5.4 Coexistence Approach (CA)**

332 The five flora lists of the different stratigraphic levels described above and given in Table 1

333 have been assigned to quantitative climatic analyses with the Coexistence Approach (CA,

334 Mosbrugger and Utescher, 1997; Utescher et al., 2014) for micro- and macrofloras

335 separately to compare local and regional climate signals. Due to the general agreements of

336 both signals, micro and macro data also have been combined to provide a higher resolution

337 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

339   studied stratigraphic interval of the Vildštejn Formation. Seven climate parameters have

340   been calculated by the CA: MAT (mean annual temperature), CMMT (mean temperature of

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

345   living relatives (NLRs), the aim of the CA is to find the climatic ranges in which a maximum

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

348   which the given fossil flora lived (for a detailed discussion and introduction to the method

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

352   requirements (1730 datasets) which are derived from meteorological stations located within

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

355   temperature-related parameters where it is usually in the range of 1 to 2 °C; results for

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

361   environmental conditions like mountainous regions (e.g., Kvaček, 2007; Grimm and Denk,

362   2012). However, methodological proxy-proxy and model-proxy comparisons as well as

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

368   as well.

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

373   with toothed vs. taxa with entire leaf margins (woody dicots) of non-pioneer vegetation

374   (Bailey and Sinnott, 1916). Wolfe (1979) devised this method and compiled 34 humid to

375   mesic floras from East Asia, including the reference datasets of Wang (1961), to build a linear

376   regression equation to predict temperature – see Eq. 6. Recently, Su et al. (2010) re-

377   evaluated original Wolfe's datasets and introduced a new equation (Eq. 7) from humid to

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

381 assemblages from Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben, the

382 application of LMA is strongly limited by a low abundance of leaf material in the studied

383 floras. We therefore experimentally used elements typified by pollen and carpological

384 remains. In such cases, the tooth and/or entire character of the leaf lamina is estimated

385 based on the known characters of their nearest living relatives (NLRs) presented in Table 1.

386 This indirect determination of leaf characters should influence the accuracy of the results

387 further than estimated in Eq. 9 and 10.

388 Eq. 6: MAT $_{LMA\,1}$ = 30.6 x P + 1.41; (r^2 = 0.98),

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

390 Eq. 8: MAT $_{LMA\,3}$ = 31.4 x P + 0.512; (r^2 = 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

394 number), P (proportion of n species with entire margin, 0 < P < 1).

395 Eq. 10: SE 2_{MAT} = $\sqrt{([1 + \varphi\,(n-1)\,P(1-P)] \times (P(1-P))/n)}$,

396 where φ = 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

399 of mean absolute deviation (MAD) was calculated as follows (Eq. 11):

19

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

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

405   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*).

421   The studied pollen spectra of the Pluto Clay of the Vonšov Member, i.e., horizons A 1-3 of

422   the Nová Ves clay pit and the middle part of the drill cores HV 2 and HV 3 sensu Stuchlik

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*,

426   *Symplocos*, *Juniperus*, *Keteleeria*, *Cryptomeria*-type, *Abies* (see Table 1, Fig. 2). Bůžek et al.

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*

433   *betuli* association, while *Pinus peuce* builds poor stands occupying higher mountain biotopes

434   over 1.500 m alt. (Horvat et al., 1974).

435   The reconstructed vegetation based on the studied plant fossils from the Tachov (Cheb–

436   Domažlice) Graben shows close affinity to those reconstructed above for the Pluto Clay.

437   The studied assemblages of the Nero Clay in the Nová Ves Member show a very similar

438   vegetation pattern corresponding to those of the Vonšov Member (see Bůžek et al., 1985,

439   Fig. 4.2). The macrofossil plant material indicates a change in floristic compositions, e.g., the

440   absence of *Quercus, Castanea, Liriodendron, Larix, Picea* contrary to new occurrences of

441   *Pinus* cf. *spinosa*, *Corylus*, and new aquatic elements, such as *Proserpinaca*, *Nymphaea*,

442   *Najas*, *Menyanthes*, *Juncus*, *Cyperus*, *Cladium*, *Caldesia*, while the pollen spectra show

443   almost identical taxa composition with higher abundances of Taxodioideae/Cupressaceae,

444   *Corylus*, Leguminosae, *Myrica*, and Rhamnaceae (see Table 1). A high frequency of the

445   mentioned aquatic and marsh elements corresponds to fluvial to oxbow lake or periphery of

446   basin environments within the zonal broad-leaved deciduous forest on their upland

447   periphery.

448   The vegetation reconstructions of the next stratigraphic level of the Nová Ves Member

449   (lignite beds) studied here are based on the floras of the Nová Ves pit (NV 9–10) and drill

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

455   analogous modern vegetation in the cool temperate zones of the northern Atlantic part of

456   the USA, like the Northern broad-leaved and Weymounth Pine forest sensu Knapp, (1965, p.

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

459   (Overbeck, 1975). Besides an increase in the abundance of *Pinus sylvestris* type, the pollen

460   spectra of the Nová Ves pit show a strong decrease in diversity. Abundances of herbaceous

461   and aquatic plants increase and arboreal riparian elements decrease (*Alnus, Salix*) indicating

462   a change especially in the azonal vegetation. The stratigraphically youngest plant fossils from

463   the Nová Ves clay pit (NV 14, C9, C$_{1-4}$, D) indicate a spreading of the coniferous forest

464   vegetation type dominated by pines (*Pinus* cf. *halepensis*, *Pinus* cf. *sylvestris*) in the

465   association with *Picea omoricoides*, *Abies* sp., and *Juniperus* cf. *communis*. The coniferous

466   forest probably overlapped with riparian vegetation with *Alnus* cf. *rugosa* and *Salix* and

467   moor and aquatic vegetation with *Menyanthes* cf. *trifoliata*, *Elatine alsinastrum*, *Andromeda*

468   *polifolia*, *Artemisia*, Cyperaceae etc. (Bůžek et al., 1985, Fig. 4.4; Table 1). These vegetation

469   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) re-

473   established by Teodoridis et al. (2011b), possible zonal vegetation assemblages are classified

474   (see Table 2). The number of elements per fossil flora varies from 42 to 126, and Appendix 3

475   shows how each element is scored for each stratigraphic level in this study. The results

476   derived from the Vonšov Member (Pluto Clay) show a relatively high abundance of arboreal

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

479   compositions of the key components correspond more or less to transitional vegetation of

480   BLDF/MMF and BLDF vegetation types (see Teodoridis et al., 2011a, Table 2). The values of

481   the zonal herb component exceed 30 % (the threshold for the BLDF and BLDF/MMF

482   vegetation types according to Teodoridis et al., 2011a). Stratigraphically comparable floras

483   from the Tachov (Cheb–Domažlice) Graben show similar results, where the values of the

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.

489 The results of the IPR vegetation analysis calculated for the floras of the Nová Ves Member

490 (Nero Clay) show a distinct increase in the abundances of SCL + LEG component (8%) and

491 zonal herbs (35 to 39 %), but values for coniferous, BLD and BLE components are almost

492 identical with those from the older levels of the Vildštejn Formation and the Tachov (Cheb–

493 Domažlice) Graben. This specific composition can be described in two ways, as BLDF and/or

494 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

499 numbers varying from 7 to 11 %, and with BLD and BLE elements in slightly lower quantities

500 (73 to 83 % and 7 to 11 %). Abundances of the coniferous component vary from 16 to 39 %

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

505 from the analysis due to the low number of zonal angiosperms elements (Table 2).

506   Generally, the results of the IPR vegetation analysis indicate several important trends of

507   vegetation changes during the Late Pliocene to Early Pleistocene period (Table 2, Fig. 7): a)

508   increase of the DRY herb component within the general increase of zonal herbaceous

509   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

513   Appendix 4) show numerous discrepancies in terms of taxonomical resolution, taxa richness,

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

516   detailed taxonomical identification (most of them are listed at species or genus level). The

517   pollen record has been described as constituted by 100 taxa belonging to 61 families (ferns

518   excluded; 35 taxa at genus level); the leaf record consists of 23 taxa attributed to 9 families

519   (ferns excluded); within the seed and fruit record 65 taxa and 37 families have been

520   described.

521   The application of the PCS approach to the fossil assemblages of the Vildštejn Formation and

522   the Tachov (Cheb–Domažlice) Graben provided separate graphical sketches for each of the

523   three studied plant organs (pollen, leaves, fruits and seeds), as shown in Fig. 3 for the

524   assemblages of the Nová Ves Member (Nero Clay, assemblage B). The discrepancies

525   between these three PCSs show very well how differently the signal of ancient vegetation is

526   recorded by different types of plant parts.

25

527   The pollen and leaf PCSs (Figs 3 and 5) are very similar within all the layers analysed and

528   depict a mesic forest variously dominated by conifers. The pollen records also yield some

529   information from the wetland areas, which is not recorded in the leaf flora at all but seems

530   to be predominantly represented by the fruit and seed record (Figs 3 and 4). Most probably

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

534   Bůžek et al. (1985). However, only for the fruit and seed record modern datasets are

535   available permitting a comparison and interpretation of PCSs in terms of palaeovegetation.

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

541   (Appendix 4) due to the lack of concentrated carpodeposits (sensu Gee et al., 2005). The

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

544   diaspores and partly by the sampling techniques (the possibility to detect a large sized seed

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

547   fruits/seeds would have hampered the transport to the deposition site because of the

548   probable absence of strong currents.

549   The Vildštejn fruit and seed-PCSs have been compared to all of the modern carpological

550   deposit-PCSs so-far obtained by analysing different types of modern vegetation and

551   environmental situations in Northern Italy (Vassio, 2012; Vassio and Martinetto, 2012), in

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

561   assumed that an "Orco 1-type" of PCS may as well occur in a different context, for example a

562   wide wetland with far-growing mesic vegetation (no modern PCSs are presently available for

563   this situation). In addition, several modern studies of seed and fruit assemblages in lakes and

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

566   documentation of the regional vegetation. Thus, the PCS analysis of the Vildštejn carpofloras

567   would suggest a detailed but very local picture of the fossil flora and vegetation.

568   The pollen PCSs (Figs 3 and 5) show in all cases more diversified transects with a dominant

569   and varied woody component. It should be emphasised that these PCSs are based on the

570   same qualitative and quantitative data which are commonly used for the interpretation of

27

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**

576   Results of the Coexistence Approach (CA) analysis of macro and micro floral assemblages for

577   the studied stratigraphic levels give narrow coexistence intervals for samples from the

578   Vonšov Member (Figs 8 and 9; Tables 3 and 4). Results from the upper part of the Nová Ves

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

581   good agreement and CA analysis of single pollen samples from the Pluto Clay (the Vonšov

582   Member) and the Nero Clay (the Nová Ves Member) of the drill core HV 2 and Nová Ves clay

583   pit have provided very similar numerical results (Tables 3 and 4). The fact that they show no

584   obvious temporal change documents relatively stable palaeoclimatic conditions during the

585   time of the Vonšov and the early Nová Ves Member depositional setting.

586   The quantitative results show temperature values considerably higher than present for

587   Tachov (Cheb–Domažlice) Graben, Pluto Clay (Vonšov Member) and Nero Clay (the lower

588   part of Nová Ves Member) with mean annual temperatures (MAT) of about 15 °C, winter

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

593 situation with MAT of 7 °C and CMMT of about -3 °C. Only summer temperatures (WMMT)

594 remain higher than the present day value of 16 °C (meteorological station of Cheb, Table 3,

595 Fig. 8). Moreover, results of this parameter consist of two coexistence intervals which

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–

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

606 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

609 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

614　　Formation and the Tachov (Cheb–Domažlice) Graben are given in Table 5. The obtained

615　　estimates for MAT show generally balanced values for the studied floras, which are

616　　independent of the used regression equations, coefficient of determination (r^2) and/or

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

621　　significantly lower values of MAT than those from CA (see Tables 3, 5 and 6). Only the MAT

622　　estimated for the upper part of the Nová Ves Member shows a comparable value to the CA

623　　data.

624

625　　**7. Discussion**

626　　**7.1 Vegetation cover**

627　　The plant spectrum of the Vonšov Member (Pluto Clay) shows relatively high abundances of

628　　the broad-leaved deciduous (BLD) component compared to relatively low amounts of the

629　　sclerophyllous (SCL+LEG) component. The general character of the zonal vegetation type

630　　should be interpreted as an ecotonal vegetation of mixed mesophytic forest and broad-

631　　leaved deciduous forest (MMF/BLDF) and/or a BLDF vegetation type for the basal Pluto Clay

632　　and for the Tachov (Cheb–Domažlice) Graben. The results are strongly affected by low

633　　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

635 these cases, because their calculation is based on the total number of zonal elements (only

636 results derived from the macrofossil plant material of the Tachov (Cheb–Domažlice) Graben

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 ≤ 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

644 results of the IPR vegetation analyses on modern vegetation from China and Japan,

645 Teodoridis et al. (2011b) reveal a distinct underrepresentation of zonal herbs in the fossil

646 record, regardless of whether dealing with leaf, pollen, or fruit assemblages. This fact can be

647 applied on the studied floras of the Vonšov Member (Pluto Clay), the Tachov (Cheb–

648 Domažlice) Graben as well as on the floras of the Nová Ves Member (Nero Clay), see Table 2.

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

651 Vonšov Member (Pluto Clay) and the Tachov (Cheb–Domažlice) Graben correspond to the

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

654 zonal conifers detected by the IPR vegetation analysis (15 to 28 %) proved the important role

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

657 beds) show a significant increase of abundance of the SCL + LEG component in account of

658 the BLD component. Besides, the high number of dry herbaceous elements from this

659 stratigraphic level can evocate changes in the composition and structure of the vegetation

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,

664 Table 4). Kovar-Eder et al. (2008) distinguished this vegetation type by three late Miocene

665 floras from Russia (Sal-Manytsh watershed, drill cores near Sinjavka and Puchljakovskij

666 farmstead). However, only the pollen flora of Puchljakovskij farmstead shows a similar

667 composition of the other key components to the floras of the Nová Ves Member

668 (Puchljakovskij farmstead: BLD 77 %, BLE 7 %, SCL+LEG 16 %, DRY HERB 24 % and MESO

669 HERB 19 %). It is evident that Xeric grasslands or steppe show higher values of DRY HERB

670 elements than our results from the Nová Ves Member, therefore this type of vegetation can

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

673 well as the above mentioned high proportion of the BLD component (73 to 83 %, Table 2,

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

679   Ericaceae, Cyperaceae, and Poaceae that is passing into moor and aquatic environments.

680   Those are well depicted by PCS results based on carpological datasets, preferentially

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)

685   within the Vildštejn Formation should evocate a structural change from dense vegetation to

686   more open light forests rather than the transition to a steppe environment. This

687   interpretation is supported also by the palaeoclimatic data which records a temperature

688   change from clearly above to close to modern values (Fig. 8, Table 3) excluding harsh

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

691   study of Kovar-Eder et al. (2006, 2008) of slightly older, i.e., latest Miocene, plant

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

694   from the Cheb Basin. The carpological flora of Sessenheim "Saugbagger-Flora" and the

695   composite flora of Auenheim (based on leaves and carpology) provide abundances of the

696   key components of BLD, BLE, SCL+LEG and zonal herb components of 76.4 %, 20.3 %, 3.3 %

697   and 13.5 %, which indicate the MMF vegetation type for Sessenheim (Teodoridis et al.,

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-

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

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

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

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

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

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

717 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

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

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

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

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

723 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

740 techniques (LMA and Climate Leaf Analysis Multivariate Program – CLAMP) contrary to

741 Nearest Living Relative approaches (e.g., Teodoridis, 2004). In fact, this seems to be the case

742 for the lower LMA temperatures of the Vildštejn Formation and the Tachov (Cheb–

743 Domažlice) Graben compared to CA results.

744 Few Plio/Pleistocene palaeobotanical sites are reported from Central Europe which were

745 studied for climatic quantifications and could serve for comparison (see Fig. 10). Some of

746 those floras have very poor age control and are assigned to Early or Late Pliocene by floristic

747 comparison, although some lack even such information, e.g. the Frankfurt 'Klärbeckenflora'

748 (Mädler, 1939; Krutzsch, 1988). Based on CA analysis Uhl et al. (2007) give MAT data of 14.4

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–

752 1160 mm (MAP) and for Pula of 10.0–15.7 °C (MAT), 0.2–4.8 °C (CMMT), 24.7–24.8 °C

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).

756 Climate values for Berga/Turingia based on CA range from 13.3 to 16.6 °C (MAT), and from

757 12.5 to 16.5 °C for the locality Willershausen. All those values are very similar to the results

758 of the studied floras from the Tachov (Cheb–Domažlice) Graben, Vonšov Member and the

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,

761 the flora of the Tachov (Cheb–Domažlice) Graben seems to be comparable with the French

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)

36

764 and Reuverian (Piacenzian, Late Pliocene), respectively. While our datasets do not show any

765 significant differences between the results from the oldest flora of the Tachov (Cheb–

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

768 from the stratigraphically older 'Saugbagger-Flora' (MAT: 15.3–15.6 °C; CMMT: 2.7 °C;

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,

779 for CMMT -0.1 to 4.1 °C, and for WMMT 21.1 to 26.4 °C (Hambach Rotton leaf flora –

780 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

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

783 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

784 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

787 values correspond well to our datasets from the upper part of the Nová Ves Member (lignite

788 beds and upper part). Temperature parameters from the older floras of the Cheb Basin

789 (Tachov /Cheb–Domažlice/ Graben, Pluto and Nero Clays) are clearly warmer than those

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

803 MAP values are published with 1036-1080 mm (Tegelen carpoflora, Tiglian C – MN17,

804 method CA – Mosbrugger et al., 2005).

805 Such regional differences of the temporal development in precipitation may well be due to

806 the increasing continental character of climate in the eastern parts of Central Europe in pace

807 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

809   floras available for comparison hinders for the moment a more insightful interpretation of

810   the terrestrial climatic changes at the Pliocene/Pleistocene boundary in Central Europe.

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.,

818   Klotz et al., 2006; Fauquette and Bertini, 2003), whereas in Northern Europe during cold

819   phases at least winter temperatures seem to be cooler than present (Pross et al., 2000; Pross

820   and Klotz, 2002).

821   Nevertheless, our data consistently show temperatures and precipitation higher than today

822   during the Pliocene and close to modern values in the younger levels, most probable at the

823   beginning of the Pleistocene. There is little evidence for much colder than present day

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

826   may reflect such cold conditions which cannot be resolved in greater detail here. Still, as

827   shown also by data from Southern Europe (Klotz et al., 2006; Fauquette and Bertini, 2003)

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

39

830 forcing behind vegetation changes by such qualitative interpretations like the one of Bůžek

831 et al. (1985). Or, to take it the other way, vegetation is reacting highly sensitively to

832 environmental changes that may be only slight climatic shifts or also other factors than

833 climate and hard to quantify.

834

835 **7. Conclusions**

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

837 •   A new floristic analysis proved the original statement given by Bůžek et al. (1982,

838 1985) and corroborate a decreasing trend of exotic elements within the studied floras, i.e.

839 from the older floras of the Tachov (Cheb–Domažlice) Graben related to Early Pliocene floras

840 of central Europe, towards floras of the Pluto and Nero Clays with estimated ages of Late

841 Pliocene (Piacenzian), to floras from the lignite beds and upper part of the Nová Ves

842 Member characterised by a massive immigration of boreal elements.

843 •   The results of IPR vegetation analysis indicate a vegetation transition from broad-

844 leaved deciduous forests (Tachov /Cheb–Domažlice/ Graben) and/or ecotonal vegetation of

845 mixed mesophytic forest / broad-leaved deciduous forests of the Pluto Clay (the Vonšov

846 Member) and the Nero Clay (the Nová Ves Member) to "more open" light forests of the

847 broad-leaved deciduous or mixed mesophytic types grown in areas of zonal to extrazonal

848 uplands during the Nová Ves Member (lignite and upper beds) setting. This vegetation

849 change is characterised by a distinct increase of abundances of SCL + LEG (11 %) and DRY

850 HERB (16 %) components. The high percentage of herbaceous component exceeding 44 % in

40

851   the Nová Ves Member could indicate a close relation to the vegetation type of the Xeric

852   grasslands or steppe. However, the relatively low value of DRY HERB component and a high

853   proportion of arboreal BLD elements safely exclude this type of vegetation.

854   •   The PCS approach displays the diversified information provided by three different

855   palaeobotanical datasets. Studies on modern assemblages suggest that the carpological PCSs

856   from wetland sediments, mainly deposited in low-energy environments, provide information

857   on the local vegetation structure limited to the azonal component of vegetation. Along with

858   the above-mentioned chronological vegetation trend the wetland communities show a slight

859   but significant loss of exotic elements and point to the development of vegetation contexts

860   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

863   present for the youngest (early Pleistocene) level. CA results for the Vonšov Member give

864   values about 15 °C for mean annual temperature, winter temperatures around 5 °C, summer

865   temperatures about 25 °C, and an annual precipitation of more than 900 mm. CA-based

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

868   well below zero (-3 °C), and summer temperatures of about 16° C in the upper part of the

869   succession. This may indicate the beginning of a cooler phase at the end of the Pliocene

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

883

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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).

1108 **Fig. 2.** Simplified pollen diagrams of drill core HV 2 (a) and Nová Ves clay pit (b). The relative

1109 abundances of trees, shrubs and herbs, as well as the AP/NAP ratio are based on the sum of

1110 gymnosperm and angiosperm taxa excluding aquatic and hydrophytes to better reflect the

1111 regional vegetation. For all other taxa the total pollen sum served as the base for calculating

1112 percentages. For details and full taxa list see Appendix 1.

1113 **Fig. 3.** Plant Community Scenario diagrams (PCSs) provided by carpological, leaf and pollen

1114 records from the Vildštejn Formation, stratigraphic level/horizon B (Vonšov Member – Pluto

1115 Clay). Notice that the PCSs do not represent actual reconstructions of the

1116 palaeoenvironment and palaeovegetation, rather they are a graphical representation of

1117 quantitative palaeobotanical data. Each typology of plant symbol is referred to a group of

1118 taxa that shares habitus, size and ecological features (Martinetto and Vassio, 2010; Vassio,

1119 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

1134 Member – lignite beds), E (Nová Ves Member – upper part). For B (Vonšov Member – Pluto

1135 Clay), see Fig. 3.

1136 **Fig. 6.** Plant Community Scenario diagrams (PCSs) provided by carpological records from the

1137 modern locality Orco 1 (San Benigno Canavese, NW Italy). – 1. vegetation-PCS obtained from

1138 the standing vegetation survey of the area (diameter length ca. 100 m) ahead of the small

1139 pond from where a fruit-bearing sediment sample was analysed. 2. vegetation-PCS obtained

1140 from the standing vegetation survey of a small wetland crossed by a brook, extended few

1141   tens of meters ahead of the small pond. 3. deposit-PCS obtained from a modern fruit and

1142   seed assemblage buried in the silty sediments of the pond. The three PCSs clearly show that

1143   this fruit and seed assemblage provides a very local record of the vegetation: the aspect of

1144   the transect is similar to the wetland vegetation close to the pond, and the signal of the

1145   mesophytic woodland which grows just 20 m apart of the pond is not well recorded by the

1146   carpological assemblage.

1147   **Fig. 7.** General vegetation changes and trends based on the IPR vegetation results of the

1148   studied floras from the Vildštejn 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), %

1151   BLE (percentages of broad-leaved evergreen woody angiosperms), % SCL+LEG (percentages

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

1156   (Tachov/Cheb–Domažlice/ Graben), B (Vonšov Member – Pluto Clay), C (Nová Ves Member –

1157   Nero Clay), D (Nová Ves Member – lignite beds).

1158   **Fig. 8.** Palaeoclimatic quantification of temperature parameters based on the Coexistence

1159   Approach, for MAT (mean annual temperature), CMMT (mean temperature of the coldest

1160   month) and WMMT (mean temperature of the warmest month) derived from the

1161   Coexistence Approach (CA). Symbols: A (Tachov/Cheb–Domažlice/ Graben), B (Vonšov

1162   Member – Pluto Clay), C (Nová Ves Member – Nero Clay), D (Nová Ves Member – lignite

1163   beds), E (Nová Ves Member – upper part), green square (based on macrofossil plant

1164   remnants), yellow circle (based on microfossil plant remnants), red rhomb (based on macro-

1165   and microfossil plant remnants), solid vertical lines (present day climatic data from the

1166   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

1173   remnants), yellow circle (based on microfossil plant remnants), red rhomb (based on macro-

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)

1179   Graben, 2. Frankfurt 'Klärbeckenflora' (Germany), 3. Gérce (Hungary), 4. Pula (Hungary), 5.

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).

1184

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

1198   seed flora), P (pollen flora), MAT (mean annual temperature), CMMT (mean temperature of

1199   the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual

1200   precipitation), HMP (precipitation of the driest month), LMP (precipitation of the driest

1201   month) and WMP (precipitation of the warmest month). The source of climatic parameters

1202   from the meteorological station of Cheb is derived from the website of the Czech

1203   Hydrometeorological Institute (http://www.chmi.cz).

1204   **Table 4.** Results of the palaeoclimatic quantification based on the Coexistence Approach for

1205   the studied fossiliferous horizons of drill core HV 2 and levels of Nová Ves clay pit (the

1206   Vildštejn Formation) based on micro (pollen) plant remains. Symbols: MAT (mean annual

1207   temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature

1208   of the warmest month), MAP (mean annual precipitation), HMP (highest monthly

1209   precipitation) LMP (lowest monthly precipitation) and (WMP) precipitation of the warmest

1210   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, $0 < P < 1$).

1215   **Appendix 1**. Raw data pollen counts of drill core HV 2 and Nová Ves clay pit (Vildštejn

1216   Formation).

1217   **Appendix 2.** List of acronyms, growth forms and plant symbols used within Plant Community

1218   Scenario (PCS). The symbol size for herbaceous plants are twice as large as they are drawn in

1219   the PCSs in order to make their visualization easier (modified after Vassio and Martinetto,

1220   2012).

1221   **Appendix 3.** Plant taxa occurring in the studied floras from the Vildštejn Formation and

1222   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 –

1231   mesophytic, HY – hygrophilous, A – aquatic); b) with the same growth form in order to

1232   define how many plant symbols of each type to be drawn in the PCS (see Appendix 2,

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).