

Foraminifers and stable isotope record of the Dubivtsi chalk (upper Turonian, Western Ukraine): palaeoenvironmental implications

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A combined micropalaeontological and stable isotope study of the Dubivtsi chalk in the Western Ukraine indicates its middle late Turonian age. One long-term and clearly distinguishable positive excursion of the isotope curve ($\delta^{13}\text{C}$) in the Dubivtsi chalk is probably equivalent to a widespread upper Turonian positive peak recorded in Western and Southern Europe and named Peak +1, Hyphantoceras Event or Hitch Wood Event. Such correlation is also supported by inoceramid fauna and increasing $\delta^{18}\text{O}$ values. Sedimentation of the pure Dubivtsi chalk occurred under highly oligotrophic conditions, reflected by the low diversity and very low abundance of planktonic and benthic foraminifera and a flood abundance of pithonellid calcispheres. These conditions probably were triggered by regression, a low level of regional tectonic activity, and near absence of uplifted areas in adjacent areas and hence the supply of nutrients to the basin was limited.

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INTRODUCTION

The Turonian is believed by many authors to be one of the warmest periods of the Phanerozoic eon (e.g., Wilson *et al.*, 2002; Bice *et al.*, 2006; Bornemann *et al.*, 2008). However, others (e.g., Stoll and Schrag, 2000; Voigt *et al.*, 2004) documented some significant climate cooling events in its upper part. Moreover, several possible stages of continental ice growth during the period were discussed (e.g., Miller *et al.*, 2005; Bornemann *et al.*, 2008). Although the problem of glaciation during the Cretaceous supergreenhouse is subject to debate (e.g., Wiese and Voigt, 2002; Bornemann *et al.*, 2008), there is no doubt that isochronous variations of $\delta^{18}\text{O}$ curves within several West and Central European basins indicate a period of late Turonian climate cooling, which is characterized by two distinct cooling phases, interpreted by Wiese and Voigt (2002) as a result of high volcanic activity, and separated by a period of climate stability. The cooling phases during the Turonian deduced from isochronous variations of $\delta^{18}\text{O}$ curves match perfectly the positive excursions on $\delta^{13}\text{C}$ isotope profiles (Wiese and Voigt, 2002, fig. 8), which show consistent stratigraphic trends, and commonly identical $\delta^{13}\text{C}$ values, and thus provide a basis for high-resolution stratigraphic correlation

(Jarvis *et al.*, 2006). One of four key carbon-isotope excursions recognized by Scholle and Arthur (1980) in the Cenomanian to lower Campanian spans the Cenomanian/Turonian boundary (e.g., Schlanger *et al.*, 1987; Arthur *et al.*, 1990; Pratt *et al.*, 1993; Peryt *et al.*, 1994). Subsequently much more correlative events have been identified between the Albian/Cenomanian and Santonian/Campanian boundaries (39 events defined, and further 33 datum levels provisionally identified by Jarvis *et al.*, 2006). The Cenomanian–Santonian carbon-isotope reference curve presented by Jarvis *et al.* (2006) is, as noted by them, remarkably similar in shape to supposedly eustatic sea level curves, increasing $\delta^{13}\text{C}$ values accompanying sea level rise.

Chemostratigraphy combined with biostratigraphy (usually based on ammonites and inoceramids) offers potential for improving global correlation and may provide a proxy for eustatic sea level variation (Jarvis *et al.*, 2006). However, planktonic foraminifera have proved to be vital in high resolution biostratigraphy of mid-Cretaceous (e.g., Moullade, 1966; Caron, 1985; Leckie, 1987) and younger marine sequences (e.g., Bolli, 1966; Premoli Silva and Sliter, 1994; Robaszynski and Caron, 1995) and useful palaeoecologic information can be obtained from ancient assemblages as simple morphotypes inhabited the near-surface waters while keeled, complex forms probably occupied deeper habitats during the mid-Cretaceous,

as today (e.g., Hart and Bailey, 1979; Leckie, 1987; Premoli Silva and Sliter, 1994). The aim of this paper is to establish an integrated detailed stratigraphy of the upper Turonian part of the Dubivtsi section (Western Ukraine) based on planktonic foraminifers and stable isotopes and to correlate it with the sections with contemporaneous strata located in NW Europe. We also present quantitative and qualitative studies of planktonic and benthic foraminifers, which compared with bulk inorganic carbon and oxygen stable isotope data make it possible to interpret the sedimentary environment in this part of the Cretaceous Boreal Sea.

GEOLOGICAL SETTING

The Dubivtsi 1 section is located in the SW margin of the East European Platform, within a tectonic unit called Border Synclinorium occurring to the NE of the Mid-Polish Anticlinorium (the inverted part of the Mid-Polish Trough; Pożaryski *et al.*, 1979), and specifically in its southeastern part – L'viv–Stryi Syncline (Pasternak *et al.*, 1987; Świdrowska *et al.*, 2008; Figs. 1 and 2). Starting from the Turonian (and ending in the late Maastrichtian) the Polish Lowland was almost entirely characterized by various chalk facies (Walaszczyk in Voigt *et al.*, 2008), and the same situation is true for the prolongation of the Mid-Polish Trough to the south-east, into the Ukraine (Świdrowska *et al.*, 2008).

In the Western Ukraine the Turonian and Coniacian strata are included into the Dubivtsi Suite with a total thickness exceeding 158 m (Ivannikov *et al.*, 1987; Gavrilishin *et al.*, 1991). The suite is overlying the Cenomanian limestones and consists of two parts. The lower subsuite of Turonian age are white and grey limestones, with flood abundances of *Pithonella* (Fig. 3) as recognized by Rozumeyko (1978); and

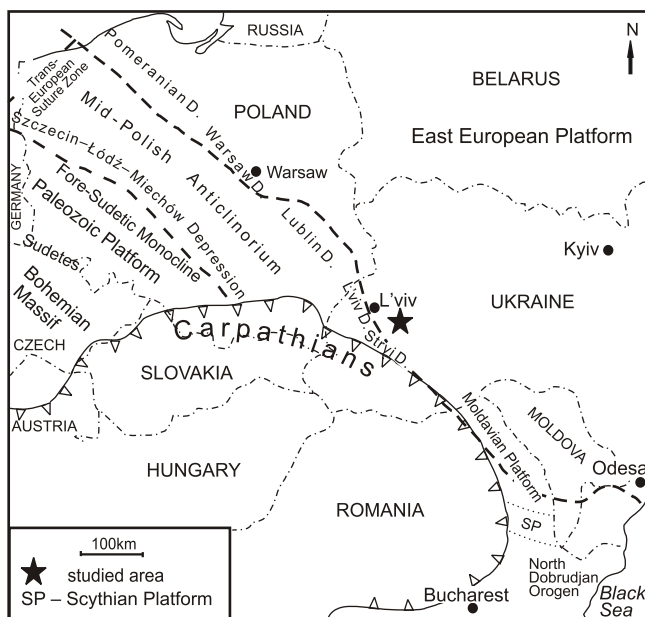


Fig. 1. Sketch tectonic map of Central Europe showing the location of the Dubivtsi section (after Świdrowska *et al.*, 2008)

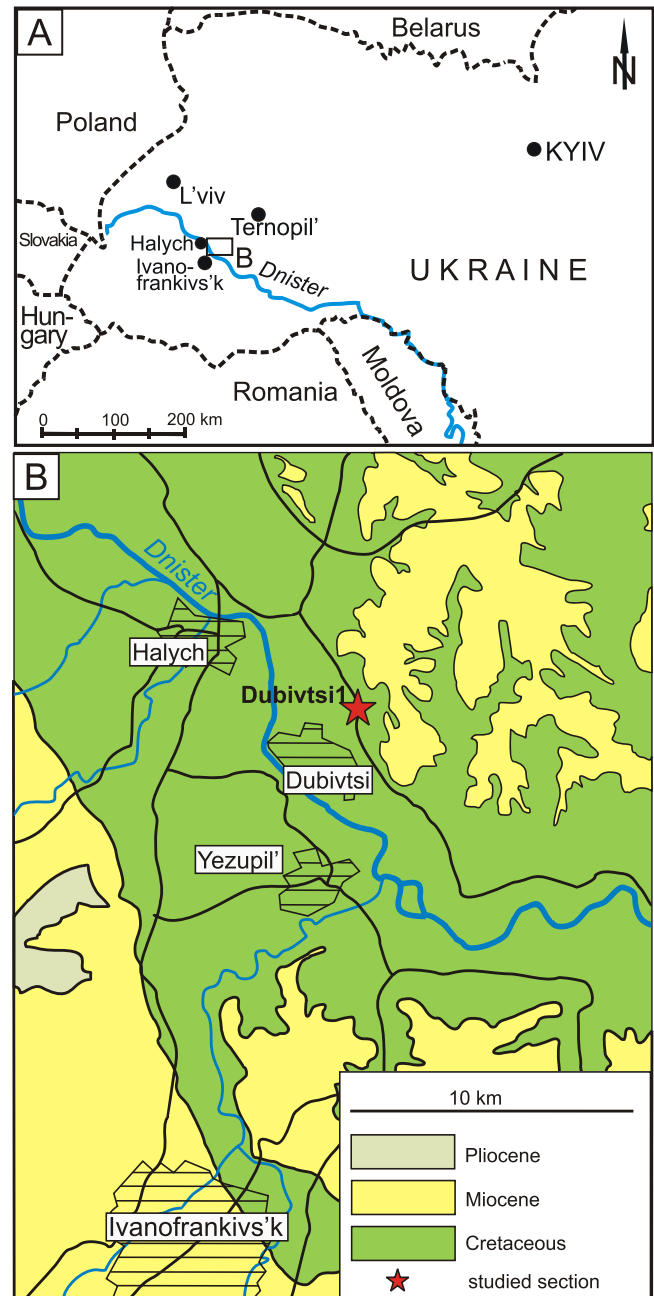


Fig. 2. Location map

A – sketch map of the Western Ukraine showing the location of the study area north of Ivanofrankivs'k; B – geological map of area between Halych and Ivanofrankivs'k with the location of the Dubivtsi section (after Vashchenko *et al.*, 2007)

with flint concretions that appear 15–20 m above the base of the suite and increase in number upward in the section (Gavrilishin *et al.*, 1991; Vashchenko *et al.*, 2007). The upper subsuite (limestones, often argillaceous, and marls with common inoceramid fragments) is of Coniacian age (Gavrilishin *et al.*, 1991).

In the huge abandoned quarry Dubivtsi (N 49°05.547', E 24°48.433') located 1 km to the east of Dubivtsi village and to the south of Halych, and which here is referred to as Dubivtsi 1 (Fig. 2), there occurs a 31 m thick section subdivided into four

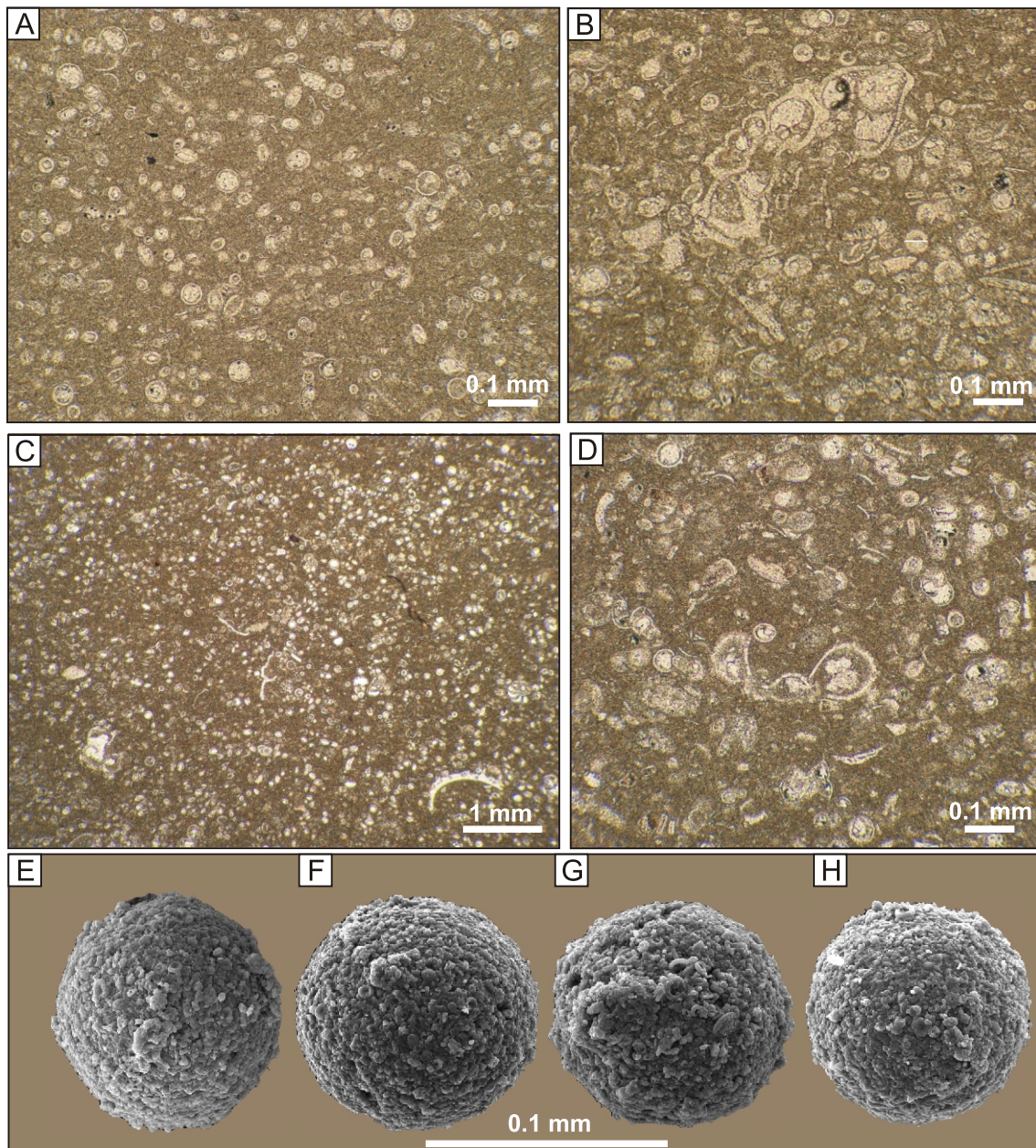


Fig. 3. Pithonellid-rich carbonates showing packstone texture from the Dubivtsi 1 section (A–D), with planktonic foraminifers (B–D) and bivalve fragments (C–D) and photomicrographs of *Pithonella ovalis* Kaufmann (E–H)

A, C – sample 8; B – sample 4; D – sample 28

lithological units: chalk (strongly lithified, with CaCO_3 content ranging from 97.8 to 99.9%); hardgrounds; inoceramid limestones (4.4 m thick) and marls (1.5 m; Fig. 4). The two lower units belong to the lower Dubivtsi Suite, and two upper units to the upper Dubivtsi Suite. The thickness of the Turonian in the region is 50–100 m (Gavrilishin *et al.*, 1991). There are ten flint layers (marked as F1–F10) relatively regularly scattered in the chalk profile (Fig. 4); however, flints do not occur in the last few metres of the chalk section. In the middle part of the Dubivtsi chalk (5.4, 6 and 14.6 m above the base of the section; Fig. 4) three clay-rich beds occur. These are designated as beds

A1 (10 cm thick), A2 (1 cm thick) and Z (3–5 cm thick; Fig. 4). There are four hardgrounds above the chalk deposits (Fig. 4). Preliminary data on the lithology and inoceramid biostratigraphy in the Dubivtsi 1 quarry succession have been presented by Pabian (2004); previous published characteristics and faunal lists of the Dubivtsi Suite (Gavrilishin *et al.*, 1991) refer to the entire suite and although most of the listed fauna can be found in the stratotype section of the suite (i.e., Dubivtsi village), detailed information supporting such an assumption (previous studies do not mention the vertical distribution of the fauna) is not available.

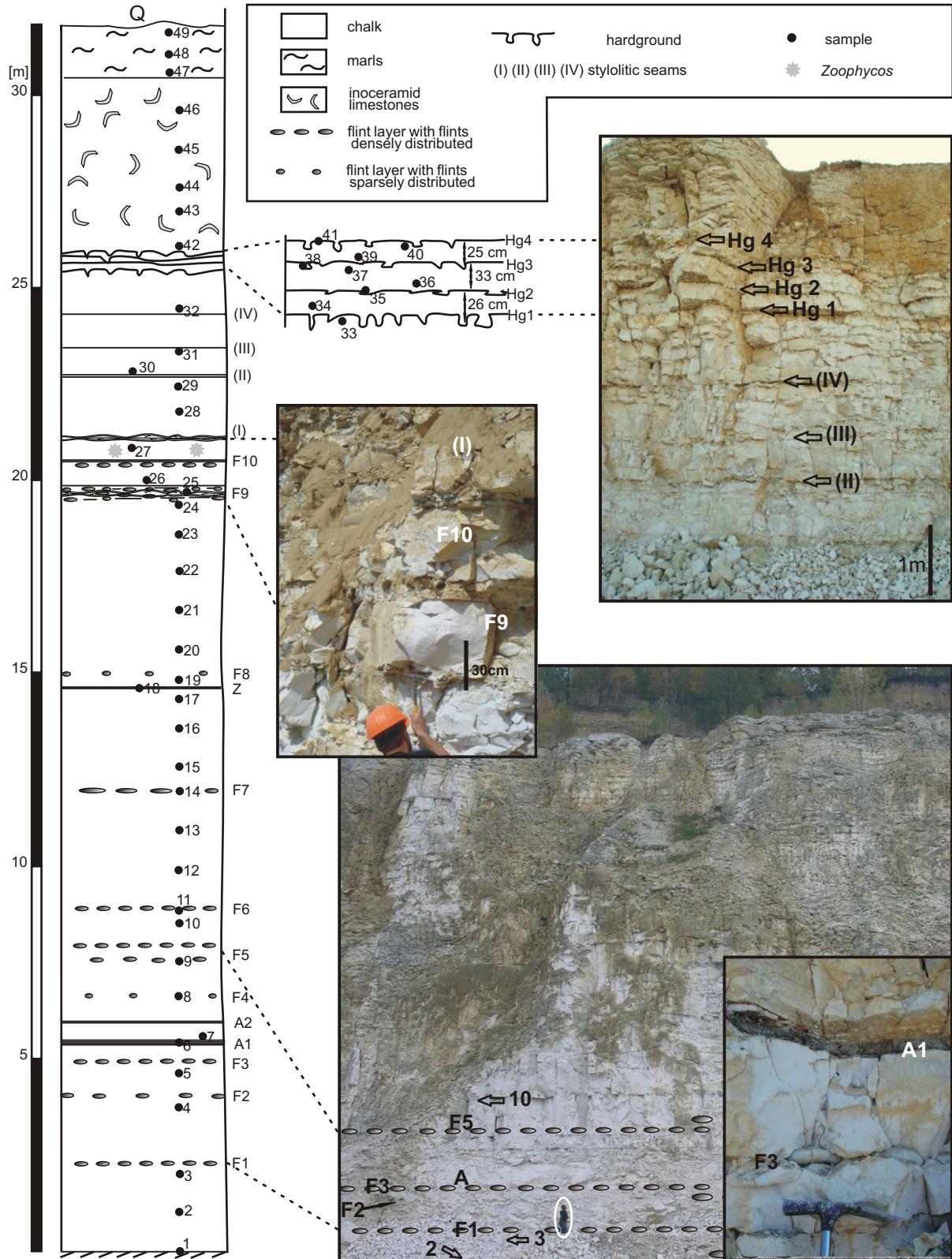


Fig. 4. The composite Dubivtsi 1 section showing characteristic strata and the sampling sites

F1-F10 – flint layers; A1, A2 and Z – clay-rich layers; I-IV – local markers – stylolitic seams; Q – Quaternary; the white ellipsoid in the lower left photo shows the senior author for scale

MATERIAL AND METHODS

Twenty seven samples from the composite section were analysed for planktonic and benthic foraminifera as well as for carbon and isotope stable isotopes; in addition, five more samples were subject to foraminiferal study. Samples were collected every 1 m. Washed residues were obtained by disaggregating the rocks by two different methods (Glauber's Salt method and liquid nitrogen method; Remin *et al.*, 2011). The residues were cleaned in an ultrasonic bath. The $\geq 63 \mu\text{m}$ fraction, containing 300 or more specimens per sample, was used for foraminiferal counts. The relative abundance of planktonic and benthic foraminifera within foraminiferal assemblages (P/B ratio), calcareous-hyaline and agglutinated forms within benthic foraminiferal assemblages, and benthic foraminiferal species within benthic foraminiferal assemblages as well as the proportion of infaunal and epifaunal morphogroups within benthic foraminiferal assemblages were calculated.

Benthic foraminifera were identified at a generic level in this study, according to Loeblich and Tappan's (1987) systematics. Allocation of foraminiferal taxa into morphogroups was

largely performed following Corliss and Chen (1988) and Nagy *et al.* (1995). The figured specimens (Figs. 5–7) are deposited in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa (ZPAL F. 63).

Carbon and oxygen stable isotopes have been analysed in bulk samples. The carbonate powder was reacted with 100% orthophosphoric acid at 70°C using a *KIEL IV* online automatic carbonate preparation line connected to the *Finnigan Mat delta plus* mass-spectrometer at the Light Stable Isotopes Laboratory of the Institute of Geological Sciences and Institute of Paleobiology, Polish Academy of Sciences, Warszawa. All isotope data were reported in per mil relative to VPDB related to NBS19. The precision (reproducibility of replicate analyses) of both carbon and oxygen isotope analyses was usually better than $\pm 0.2\%$.

Abundances of total carbon were determined by using an *Eltra CS-500 IR* analyzer with a total inorganic carbon module, at the University of Silesia (Sosnowiec, Poland). Calcium carbonate content was calculated as $\text{CaCO}_3 = 8.333 \times \text{total inorganic carbon}$, assuming that all carbonate is present as calcite or aragonite.

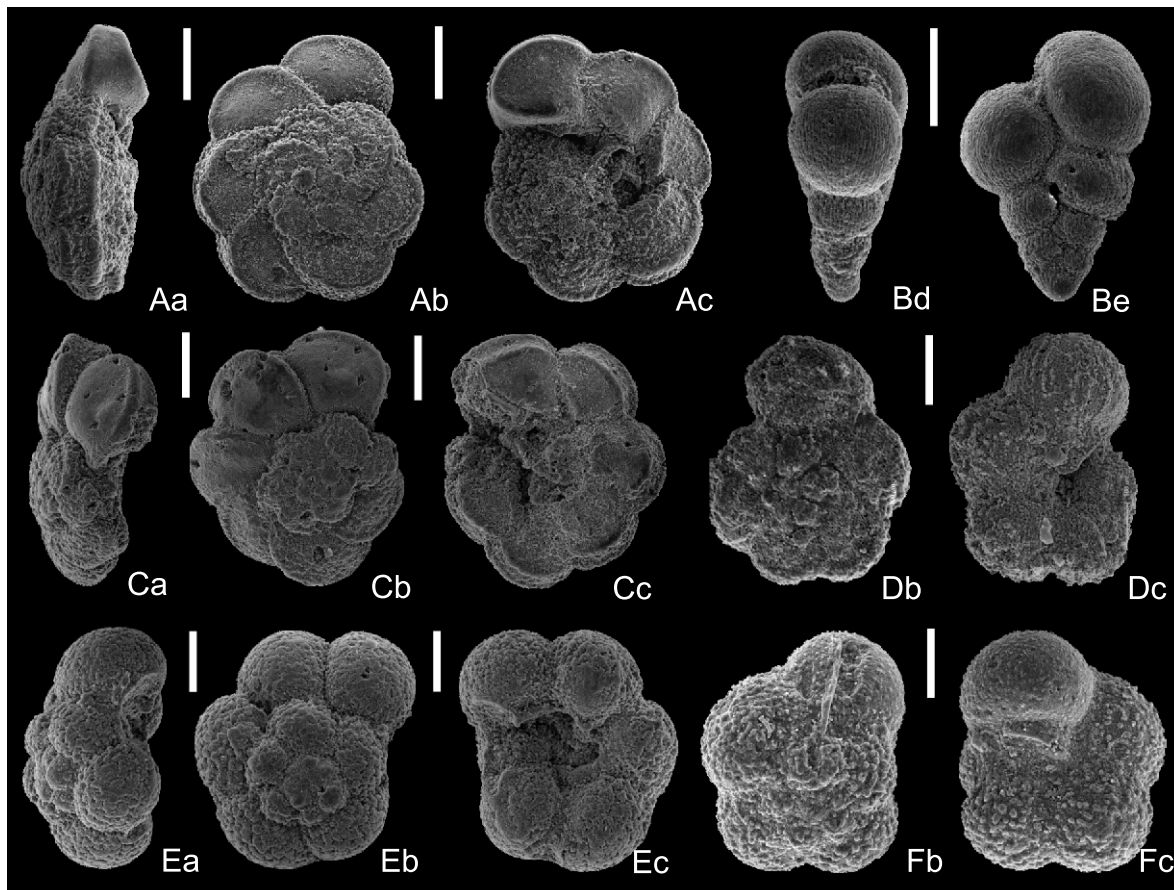


Fig. 5. Planktonic foraminifera of the Dubivtsi chalk

A – *Marginotruncana coronata* (Bolli); **B** – *Heterohelix reussi* (Cushman); **C** – *Dicarinella imbricata* (Mornod); **D** – *Falsotruncana* sp.; **E** – *Whiteinella brittonensis* (Loeblich and Tappan); **F** – *Whiteinella baltica* Douglas and Rankin; A, C, D – sample 1; B – sample 32, E – sample 5, F – sample 20; scale bar – 100 μm ; a – edge view, b – dorsal view, c – ventral view, d – side view, e – lateral view

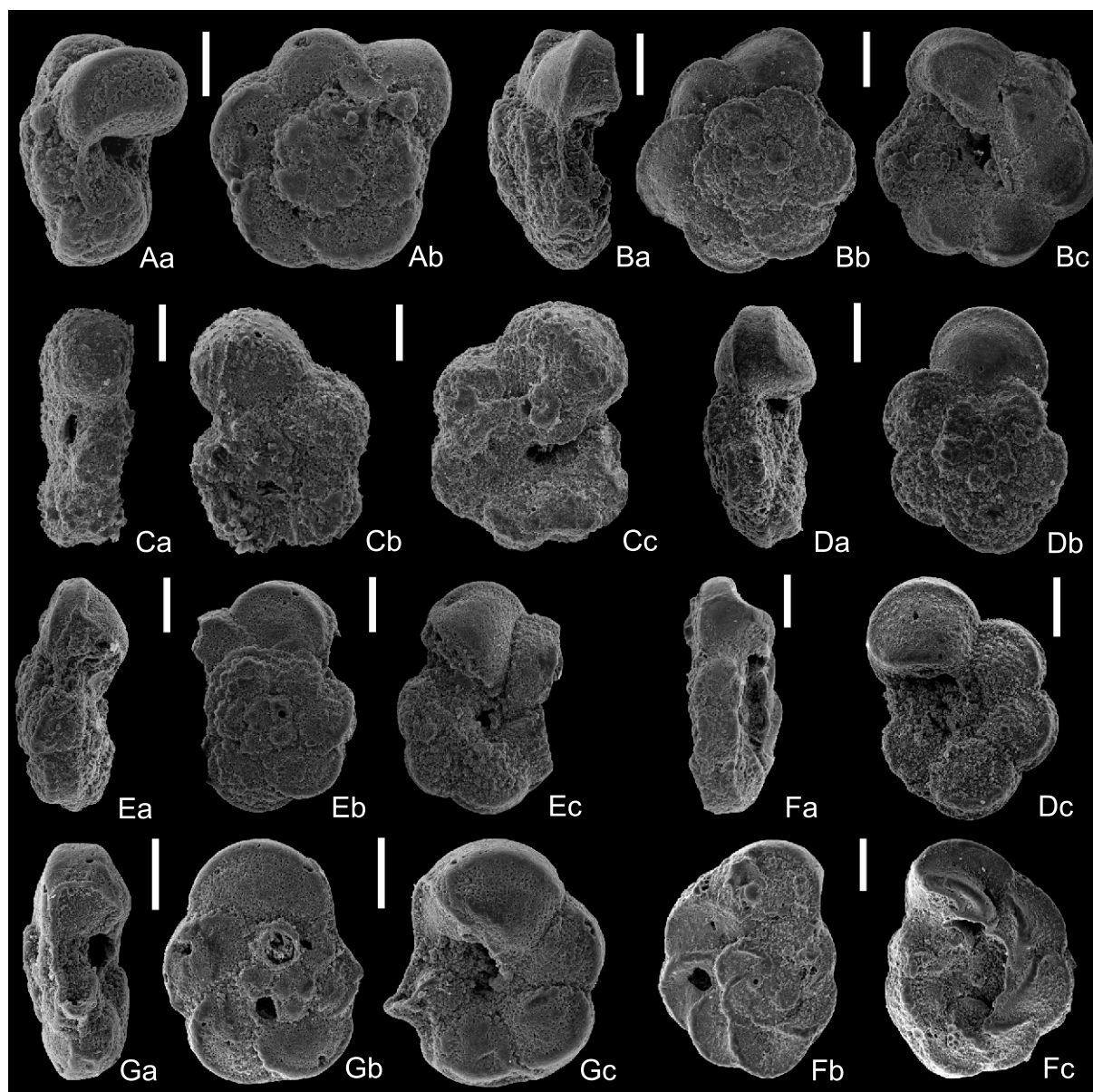


Fig. 6. Planktonic foraminifera of the Dubivtsi chalk

A – *Helvetoglobotruncana helvetica* (Bolli); B – *Dicarinella imbricata* (Mornod); C – *Falsotruncana* sp.; D – *Marginotruncana marginata* (Reuss); E – *Dicarinella hagni* (Scheibnerova); F – *Marginotruncana pseudolinneiana* Pessagno; G – *Dicarinella canaliculata* (Reuss); A, B, D–G – sample 1, C – sample 4; other explanations as in Figure 5

RESULTS

FORAMINIFERS

The Dubivtsi chalk yielded well-preserved benthic and planktonic foraminiferal assemblages that show low diversity and very low abundance and very abundant pithonellids (Figs. 3, 5, 6, 8 and 9). Thirteen species of planktonic foraminifera were recorded: *Helvetoglobotruncana helvetica* (Bolli), *Marginotruncana coronata* (Bolli), *M. marginata* (Reuss), *M. pseudolinneiana* Pessagno, *Dicarinella imbricata* (Mornod), *D. hagni* (Scheibnerova), *D. canaliculata* (Reuss), *Whiteinella baltica* Douglas and Rankin, *W. brittonensis* (Loeblich and Tappan),

Falsotruncana sp., *Globigerinelloides caseyi* (Bolli, Loeblich and Tappan), *Heterohelix reussi* (Cushman), *Hedbergella delrioensis* (Carsey) (most of them are shown in Figs. 5 and 6). The small-sized, simple heterohelicids, planispiral *Globigerinelloides* and trochospiral *Whiteinella* occur in the entire section (Fig. 8), although they are very rare. Keeled forms of planktonic foraminifera are common only in the lowest and higher part of the chalk succession (Figs. 8 and 9). In most samples the P/B ratio in the 0.06–0.75 mm size fraction is about 20%, except for the lowest sample, where it is almost 50% (Fig. 9).

Benthic foraminiferal numbers per gram dried sediment in the Dubivtsi chalk are very low and do not exceed 4 individuals/g. Eleven species of benthic foraminifera have been re-

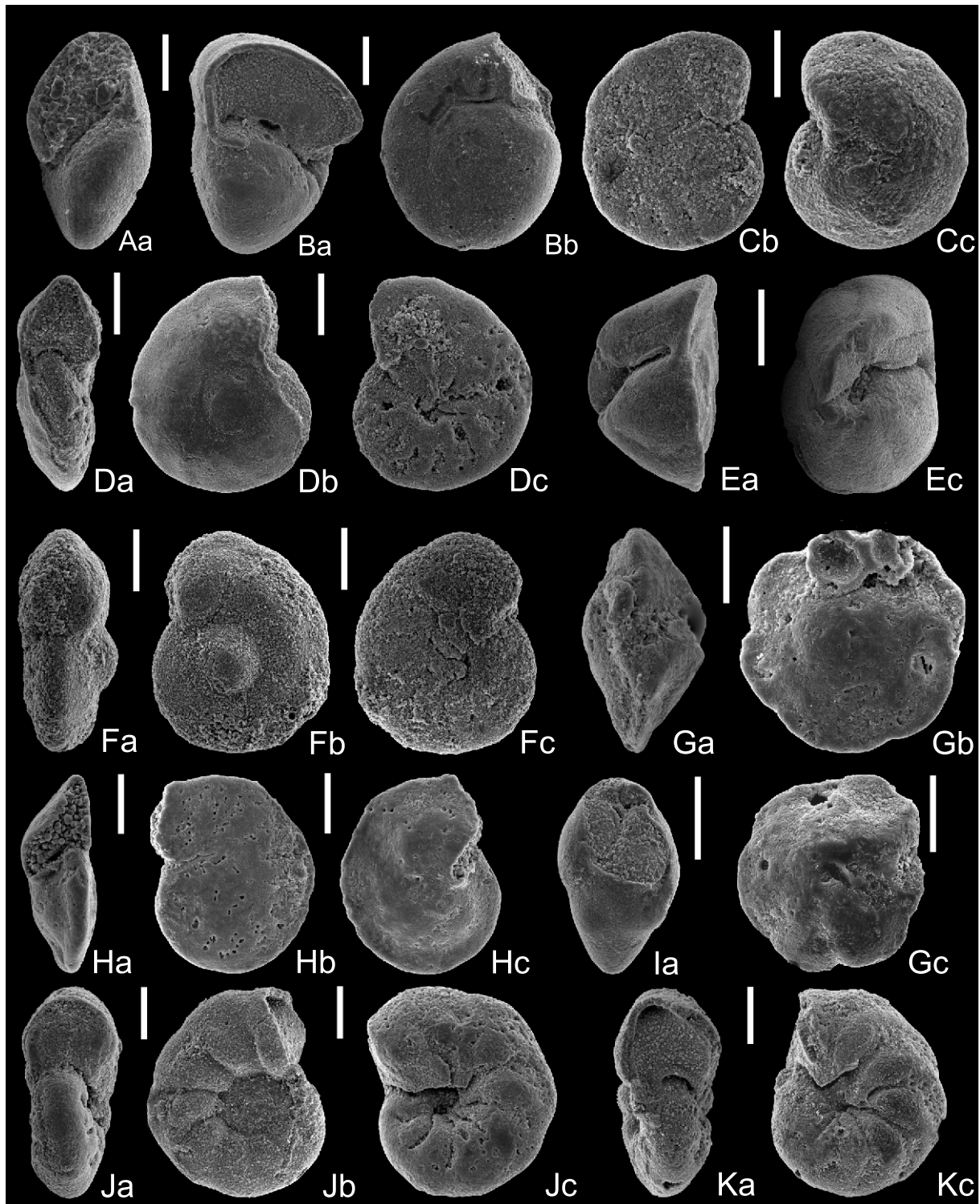


Fig. 7. Benthic foraminifers of the Dubivtsi chalk

A – *Valvulineria lenticula* (Reuss); **B** – *Gyroidinoides nitidus* (Reuss); **C** – *Cibicides polyrraphes* var. *polyrraphes* (Reuss); **D** – *Gavelinella vesca* (Bykova); **E** – *Globorotalites hangensis* Vassilenko; **F** – *Gavelinella vesca* (Bykova); **G** – *Eponides karsteni* (Reuss); **H** – *Cibicides polyrraphes* var. *polyrraphes* (Reuss); **I** – *Praebulimina reussi* (Morrow); **J** – *Gavelinella ammonoides* (Reuss); **K** – *Gavelinella ammonoides* (Reuss); A – sample 5, B – sample 19, C, H – sample 1, D – sample 20, E – sample 30, F – sample 10, G – sample 27, I – sample 28, J – sample 20, K – sample 14; other explanations as in [Figure 5](#)

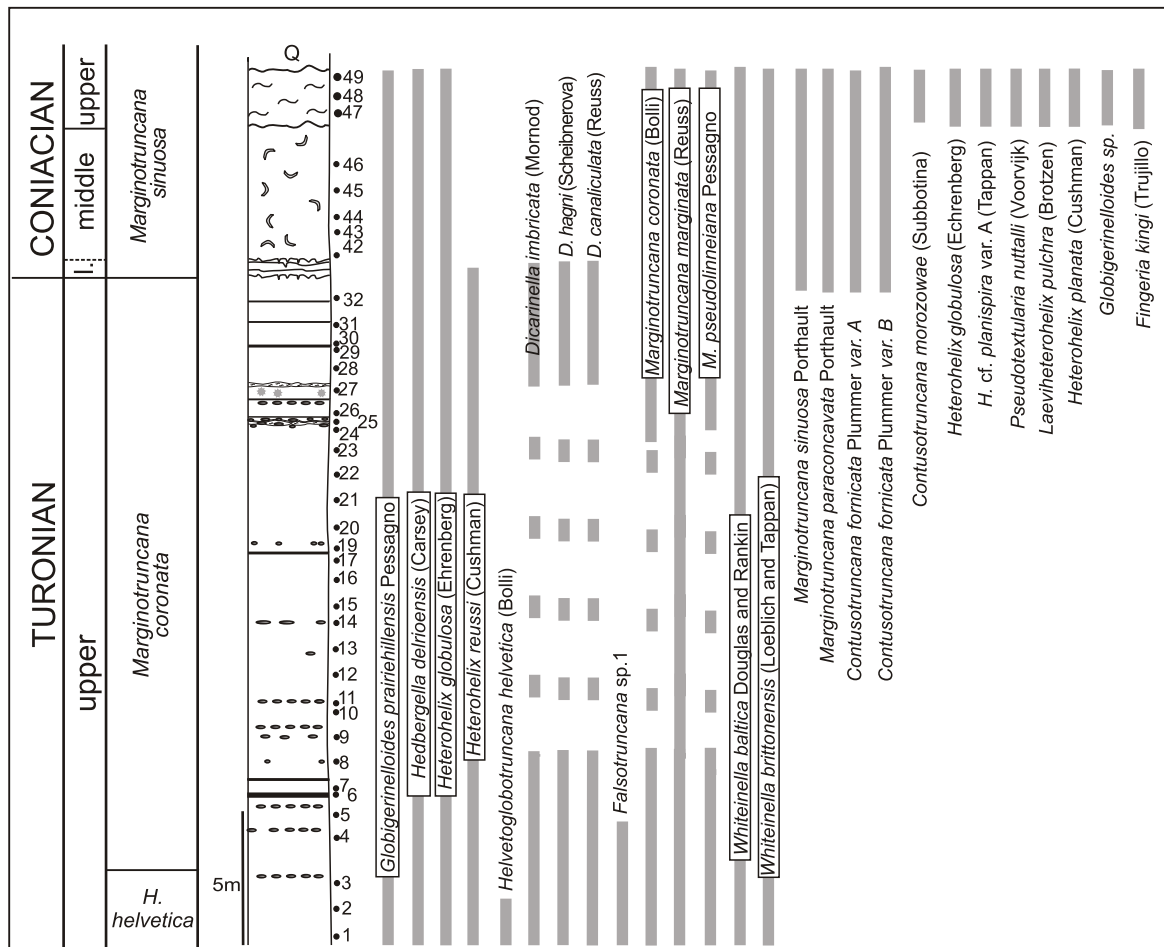


Fig. 8. Distribution of planktonic foraminifers in the Dubivtsi 1 section

Explanations as in Figure 4

corded in studied material. Nine species represent calcareous forms and only two agglutinated species have been found (Fig. 9). Calcareous foraminifers form 90% of the assemblages and three species, i.e., *Gavelinella ammonoides* (Reuss), *G. vesca* (Bykova) and *Gyroidinoides nitidus* (Reuss), dominate the assemblages. Their contribution to the total varies between 60 and 80% (Fig. 9D). The agglutinated component of the benthic foraminiferal assemblages is very low; only two species are recorded: *Arenobulimina* sp. and *Marssonella oxycona* (Reuss). Their contribution varies between 1 and 10% of the assemblages (Fig. 9D).

STABLE ISOTOPES

The results of stable isotope study are shown in Figure 10 and. The $\delta^{13}\text{C}$ values for the Dubivtsi chalk vary between +1.94 and +2.78‰; the average is $2.34 \pm 0.26\text{‰}$ (Fig. 10). The curve shows a steady and continuous rise through the sampled interval from the bottom of the profile (the $\delta^{13}\text{C}$ value of the lowest studied sample was 1.96‰) to the positive excursion with values of +2.78‰ in the middle part of Dubivtsi chalk, followed by a gradual and continuous decline down to +1.94‰ near the top of the Dubivtsi chalk, although the highest sample in the Dubivtsi chalk section shows slight increase to +2.0‰

(Fig. 10). The $\delta^{18}\text{O}$ values range from -2.67 to -1.56‰ throughout the studied section (Fig. 11); the average is $-2.09 \pm 0.31\text{‰}$.

INTERPRETATION AND DISCUSSION

STRATIGRAPHY

The inoceramid fauna occurring in the Dubivtsi profile contains *Mytiloides striatoconcentricus* (Gümbel), which is globally known from the upper Turonian to the lowermost Coniacian (Walaszczyk, 1992). In addition, the upper Turonian sediments of the area of Poland, Germany, France and England are similarly developed to the middle part of the upper Turonian, which can indicate (Pabian, 2004; Walaszczyk, pers. comm.) a middle late Turonian age for the Dubivtsi section. This age is also supported by the herein described planktic foraminiferal correlation with the Middle Vistula River Valley section, Central Poland. Taxonomically, the foraminiferal assemblages recorded in the Dubivtsi 1 section are characteristic for global Turonian strata (Fig. 12). The last appearance of *Helvetoglobotruncana helvetica* is recorded in the lowest part of the profile (in sample 3), defining the upper boundary of the

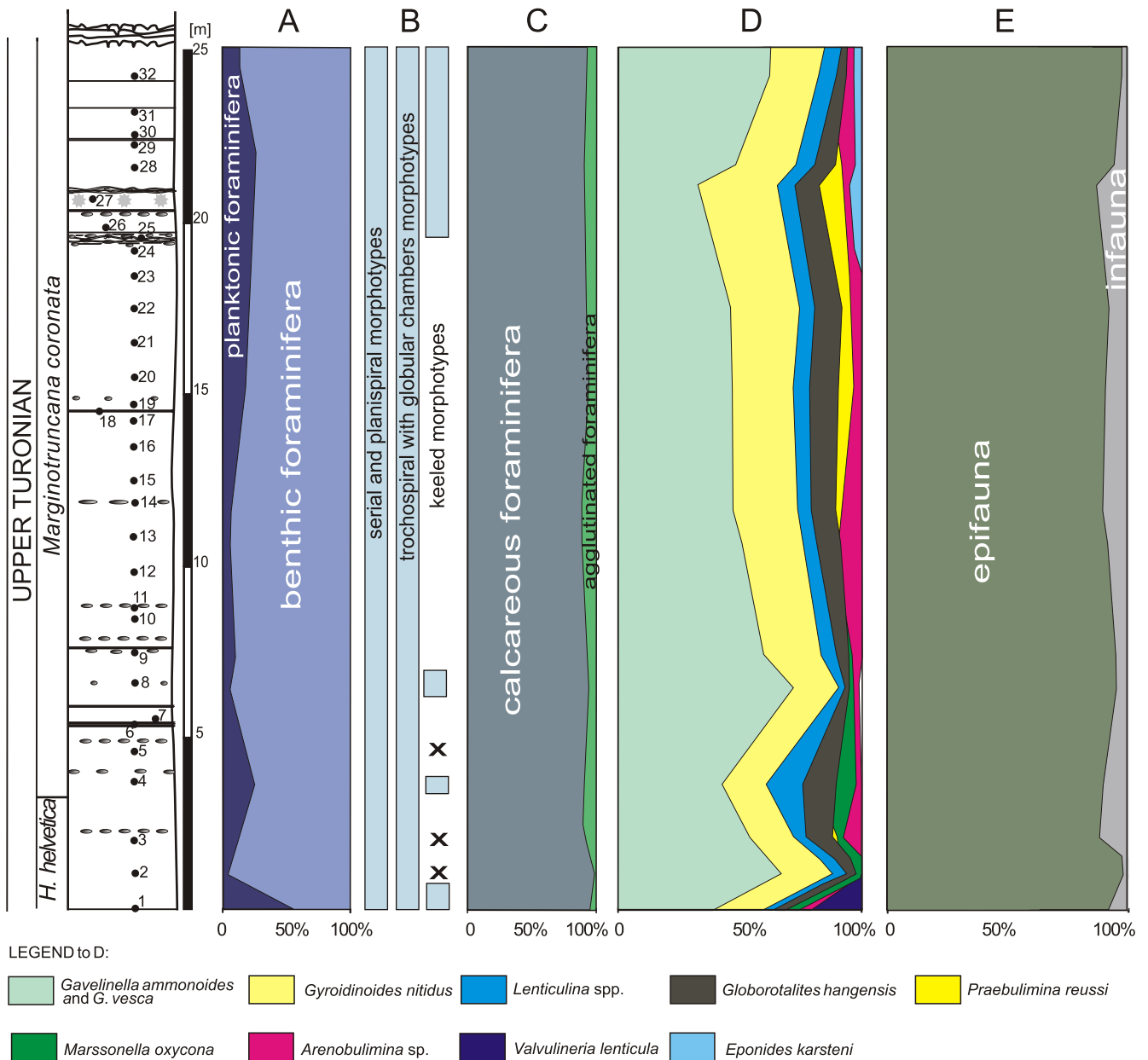


Fig. 9. Changes in assemblages of planktonic and benthic foraminifers of the Dubivtsi chalk

A – P/B ratio; B – distribution of particular morphotypes of planktonic foraminifera; C – proportion of calcareous and agglutinated foraminifera in benthic foraminiferal assemblages; D – abundance fluctuation of species and group of species of benthic foraminifera in foraminiferal assemblages; E – proportion of epifaunal and infaunal morphotypes in benthic foraminiferal assemblages; other explanations as in Figure 4

standard foraminiferal Total Range Zone *Helvetoglobotruncana helvetica*. The last appearance of *H. helvetica* and the absence of representatives of the genus *Praeglobotruncana* in the analysed profile indicate that it corresponds to the boundary interval between local *Helvetoglobotruncana helvetica* and *Marginotruncana coronata* zones distinguished in the Middle Vistula River Valley (Peryt, 1980; Walaszczyk and Peryt, 1998). The boundary of the above-mentioned zones is located in the Middle Vistula River Valley section in the middle part of the upper Turonian within the inoceramid zone *Inoceramus costellatus* (Fig. 11). Thus based on the occurrence of *Mytiloides striatoconcentrinus* and the planktic foraminiferal correla-

tion with the Middle Vistula River Valley profile, the Dubivtsi chalk can be placed in the middle part of upper Turonian within the *Inoceramus costellatus* Zone (Fig. 12).

The long-term and clearly distinguishable positive excursion of the $\delta^{13}\text{C}$ values recorded in the middle part of Dubivtsi chalk, representing the middle part of the upper Turonian, can be correlated with a widespread positive peak recorded in the middle part of upper Turonian, in the upper *Subprionocyclus neptuni* Zone, in south-east England (Dover – Gale, 1996; Culver and Trunch – Jarvis *et al.*, 2006) called the Hitch Wood Event (Gale, 1996; Fig. 10). This excursion (Peak +1; Jarvis *et al.*, 2006) defining the Hitch Wood Event in England is also very well-developed in

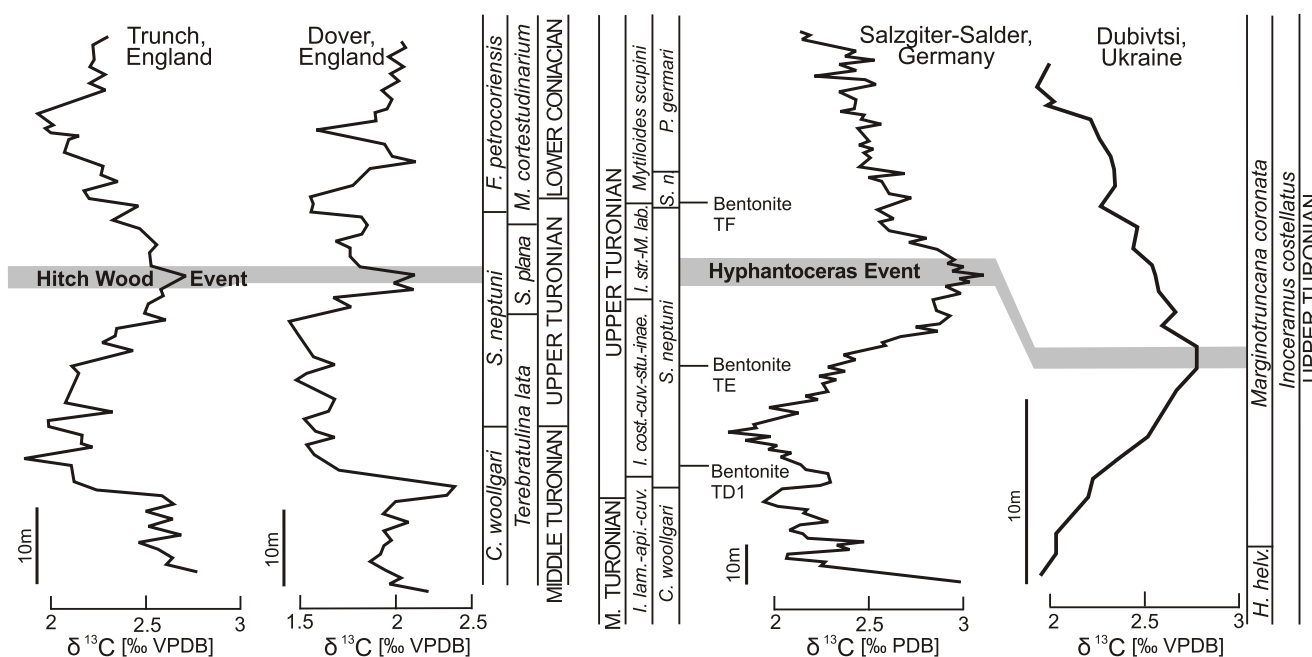


Fig. 10. Correlation of $\delta^{13}\text{C}$ curve for Dubivtsi chalk with the curves characteristic for Salzgitter-Salder, NW Germany (after Voigt and Hilbrecht, 1997; Walaszczyk *et al.*, 2010), Trunch, SE England (after Jarvis *et al.*, 2006) and Dover, SE England (after Jenkyns *et al.*, 1994)

C. woollgari – *Collignoceras woollgari*; *S. neptuni* (*S. n.*) – *Subprionocyclus neptuni*; *F. petrocoriensis* – *Forresteria petrocoriensis*; *S. plana* – *Sternotaxis plana*; *M. cortestudinarium* – *Micraster cortestudinarium*; *I. lam.-api.-cuv.* – *Inoceramus lamarcki-apicalis-cuvieri*; *I. cost.-cuv.-stu.-inae.* – *Inoceramus costellatus-cuvieri-stuemckei-inaequivalvis*; *I. str.-M. lab.* – *Inoceramus striatoconcentricus-Mytiloides labiatoidiformis*; *P. germari* – *Prionocyclus germari*; *H. helv.* – *Helvetoglobotruncana helvetica*; limits of Peak +1 = Hyphantoceras Event = Hitch Wood Event as drawn by Jarvis *et al.* (2006)

NW Germany in Salzgitter-Salder (Voigt and Hilbrecht, 1997; Wiese, 1999; Wiese and Kaplan, 2001; Walaszczyk *et al.*, 2010), where it is called the Hyphantoceras Event, as well as in Northern Spain (Wiese, 1999), the Czech Republic (Wiese *et al.*, 2004) and, in addition, it can be clearly seen in Turonian carbon-isotopes profiles from Italy (Jenkyns *et al.*, 1994; Stoll and Schrag, 2000) and Tibet (Wendler *et al.*, 2011).

The increase in the $\delta^{18}\text{O}$ values in the Dubivtsi 1 profile coincides with positive $\delta^{13}\text{C}$ values reflecting the Hyphantoceras Event or Hitch Wood Event (Fig. 8). In many locations in Western Europe the positive carbon-isotope excursion related to the Hyphantoceras/Hitch Wood Event is accompanied by increasing $\delta^{18}\text{O}$ values (see Wiese and Voigt, 2002, fig. 3) that are interpreted as due to climatic cooling.

PALAEOENVIRONMENTS

The middle and upper Turonian bulk rock $\delta^{18}\text{O}$ curves for Western and Central Europe (Voigt and Wiese, 2000; Wiese and Voigt, 2002) show two distinct cooling phases. The first cooling phase (termed Phase I) is located in the higher middle Turonian whereas the second-one (Phase III) is in the higher *S. neptuni* Zone. Phase III is clearly identified in Salzgitter-Salder (NW Germany; Voigt and Hilbrecht, 1997; Walaszczyk *et al.*, 2010), Liencres (Northern Spain; Wiese, 1999) and Kent (SE England; Jenkyns *et al.*, 1994; Fig. 11). It can be also recognised in the Dubivtsi 1 section taking into account that the $\delta^{18}\text{O}$ values in the lower and middle part of the Dubivtsi chalk section are the highest in comparison to the Upper Cretaceous

strata exposed near Halych that represent a long stratigraphical interval, from the lower Cenomanian to the lowest Campanian (Fig. 11). Subsequently, they drop by about 0.7‰ (Figs. 10 and 11). It is remarkable that this increase coincides with changes in planktonic foraminiferal assemblages in the Dubivtsi 1 section (Fig. 11). All keeled taxa, which are believed to have been the deepest-dwelling planktonic foraminifers (e.g., Bé, 1977; Hart and Bailey, 1979; Leckie, 1987; Premoli Silva and Sliter, 1999), disappear in the lowest part of the Dubivtsi chalk and appear again in its higher part. We relate the absence of keeled forms (marginotruncanids, dicarinelids) with a sea level drop. The Dubivtsi 1 section originated in a stable cratonic environment (East European Platform) and thus changes in the palaeobathymetry of the basin were mainly driven by global eustasy. Consequently, the sea level fall identified in the Dubivtsi 1 section supports the idea of a large drop in global sea level which is coincident with a climate cooling. The progressive shallowing associated with cooling Phase III is also observed in other European sections (Voigt and Wiese, 2000). Moreover, intense sea level changes in the upper Turonian, with two second-order regressive peaks were documented from the upper part of the Eagle Ford Shale and the lower part of the Austin Chalk in the Western Interior Basin, Dallas area, Texas (Hancock and Walaszczyk, 2004).

This cooling phase (reflected in positive $\delta^{18}\text{O}$ fluctuations) co-occurring with sea level fall was interpreted as being due to global changes in ocean circulation (Voigt and Wiese, 2000) and also as an evidence for glaciation, with ice sheets about half the size of the modern Antarctic ice cap (Stoll and Schrag,

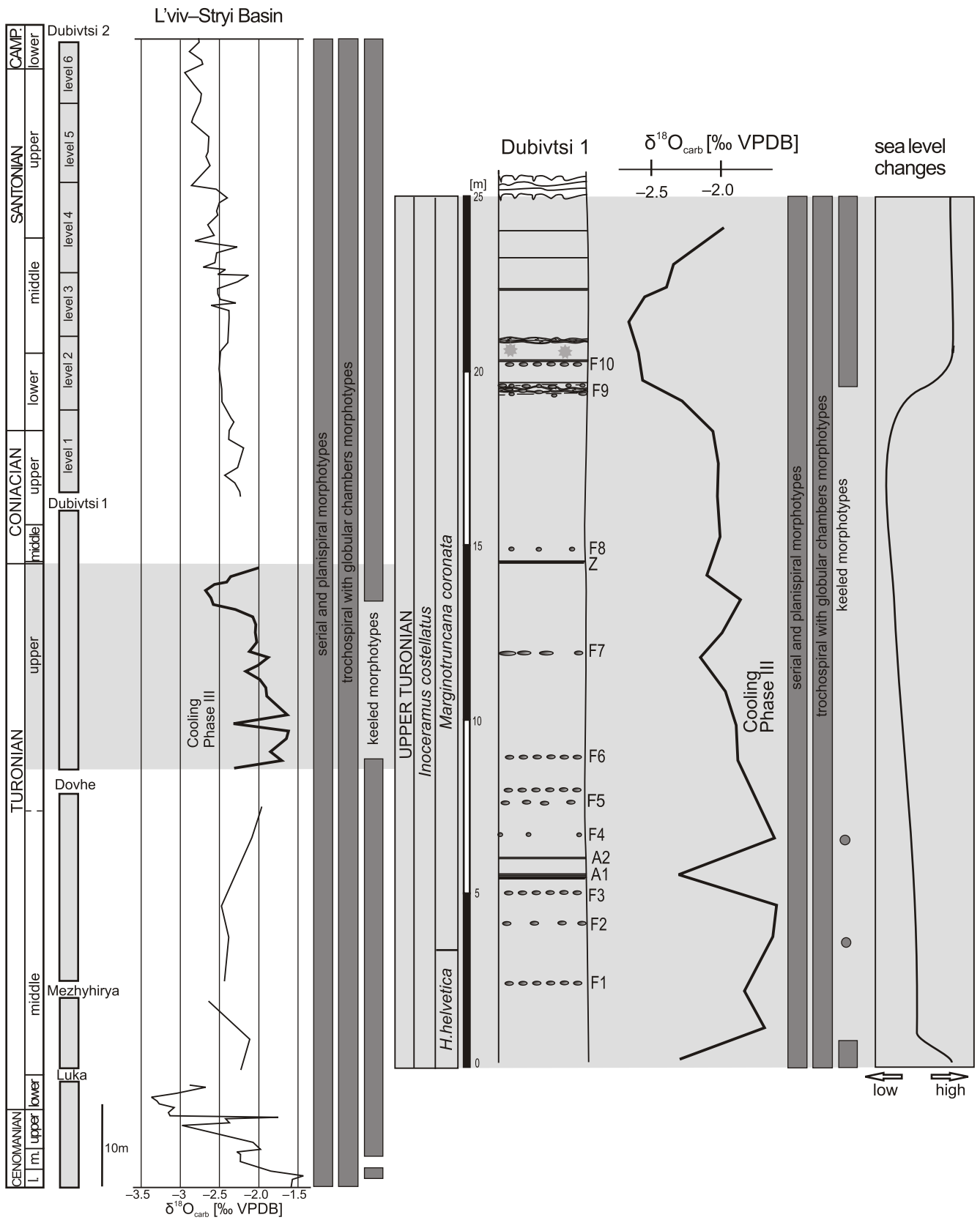


Fig. 11. $\delta^{18}\text{O}$ curve measured for the Cenomanian–lower Campanian section of the L'viv–Stryi Basin (after unpubl. data of Z. Dubicka) and distribution of particular morphotypes of planktonic foraminifera showing the heaviest values of $\delta^{18}\text{O}$ and the lack of keeled morphotypes of planktonic foraminifera in the middle part of the upper Turonian

Explanations as in Figure 4

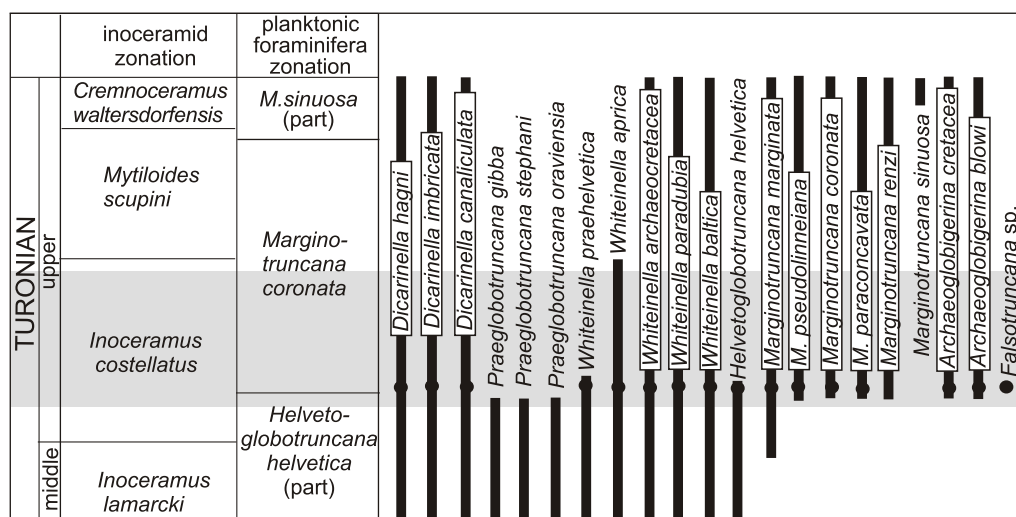


Fig. 12. Ranges of planktonic foraminifers in the Middle Vistula River Valley section (after Peryt, 1980; Walaszczyk and Peryt, 1998) and the inferred stratigraphic range of the Dubivtsi chalk (grey field)

The inoceramid and planktonic foraminifer zonation after Walaszczyk and Peryt (1998)

2000; Bornemann *et al.*, 2008). However the lack of glacial deposits does not support the idea of Cretaceous ice sheets.

In contrast to Western European sections, the Upper Cretaceous strata of the Dubivtsi 1 section were deposited in a stable cratonic environment (East European Platform) and thus the changes in palaeobathymetry of the basin were mainly driven by global eustasy. Consequently the sea level fall assumed for Dubivtsi coincides with the large drop in global sea level and climate cooling. On the one hand we can interpret the climate cooling as due to changes in ocean circulation as opposed to volcanic theory (Wiese and Voigt, 2002) but on the other hand that sea level low was triggered by the growth of ice sheets. We concur with Stoll and Schrag (2000) and Bornemann *et al.* (2008) that the late Turonian was one of the most probable intervals of the occurrence of glaciations during the Late Cretaceous.

The distribution of planktonic foraminifers in modern and past marine waters depends mainly on temperature, salinity, water depth, and primary productivity in surface waters (Bé, 1977; Hemleben *et al.*, 1989; Arnold and Parker, 1999). The diversity of modern planktonic foraminifer assemblages is highly connected with latitude and decreases from the tropics towards the poles. It is believed that vertical migration in the water column of planktonic foraminifers is related to shell morphology (Bé, 1977; Caron and Homewood, 1983; Leckie, 1987; Premoli Silva and Sliter, 1994; Price and Hart, 2002). Keeled planktonic foraminifera are assumed to be deep-dwellers whereas serial, planispiral and trochospiral forms with globular chambers are considered to be more shallow-dwelling species, inhabiting the upper 100 m of the ocean water column. The taxonomic composition of Cretaceous planktonic foraminiferal assemblages correlated with sedimentological data representing transgressive-regressive cycles have often been described (e.g., Hart and Bailey, 1979; Hart, 1980; Minard, 1980; Owens and Gohn, 1985; Walaszczyk, 1987; Georgescu, 2006). Generally keeled morphotypes are not found in shallow shelf environments and their increase in num-

ber is observed with increasing water depth and distance from the shoreline (Leckie, 1987).

Their diversity and distribution are also highly connected with the supply of nutrients into the basin. Thus a change in the planktonic foraminiferal assemblage can also indicate a change in palaeotrophic conditions in the surface waters. Biserial heterohelicids and thin-walled hedbergellids are r-strategists (e.g., Boersma and Premoli Silva, 1989; Petrizzo, 2002). They are characterized by small-sized, simple tests, short life span, and by reproducing quickly enough to closely track their nutritional resources and inhabit more nutrient-rich water. They thrive best under meso- and eutrophic conditions (Leckie, 1987; Nederbragt, 1991; Leckie *et al.*, 1998; West *et al.*, 1998; Premoli Silva and Sliter, 1999; Petrizzo, 2002). The assemblages of planktonic foraminifers from the Dubivtsi chalk are characterized by very low-diversity and low abundance, especially of r-strategists. While the absence of planktonic keeled forms is probably related to the sea level drop, the low-occurrence of r-strategists (heterohelicids, hedbergellids, globigerinelloidids) which are shallow-dwelling species can indicate low primary production and a highly oligotrophic environment.

Benthic diversity is coupled to pelagic diversity and abundance in the modern oceans, albeit in a complex way (e.g., Graf, 1992; Rosenberg, 1995). Oxygen and food availability are the most important factors controlling modern benthic foraminiferal distribution on the sea floor (e.g., Jorissen *et al.*, 1995; Moodley *et al.*, 1998; van der Zwaan *et al.*, 1999; Brüchert *et al.*, 2000). Oxygen deficiency alone almost never acts as a limiting agent hampering the metabolism. The greatest control comes from the changes in the amount of food available as well as from possible changes in the quality of food. The ultimate downward organic flux rate controls both the food availability and the oxygen concentrations at the sea floor (Barmavidjaja *et al.*, 1992). A high flux of organic matter causes low oxygen concentrations within the sediment pore waters because oxygen is used in oxidation of the organic mate-

rial. It suggests that a key factor controlling benthic biodiversity and abundance in the geological past must have been palaeoproductivity in the overlying water column (Herguera and Berger, 1991; Loubere, 1991; Gale *et al.*, 2000).

Benthic foraminifers with an infaunal life position living within the sediment are thought to be more tolerant of oxygen deficiency (Kaiho, 1991; Kaminski *et al.*, 1995). Infaunal species dominate in assemblages associated with relatively high organic-carbon flux, and epifaunal ones in more oligotrophic environments (e.g., Thomas, 1990; Jorissen *et al.*, 1995). In highly oligotrophic regions all food particles will be consumed or oxidised at the sediment surface and the underlying sediment will contain only small quantities of organic matter, which cannot sustain an abundant infaunal population. Consequently the population of benthic foraminifera is dominated by epifaunal morphotypes. Rounded trochospiral, plano-convex trochospiral, biconvex trochospiral/planispiral, milioline and tubular morphotypes mainly live epifaunally. Rounded planispiral, flattened ovoid, tapered and cylindrical, flattened tapered morphotypes live dominantly infaunally, although exceptions do occur (Corliss and Chen, 1988; Nagy *et al.*, 1995).

We interpret *Gavelinella ammonoides* (Reuss), *G. vesca* (Bykova), *Gyroidinoides nitidus* (Reuss), *Globorotalites hangensis* Vassilenko, *Eponides karsteni* (Reuss), *Cibicides polyrraphes* (Reuss) and *Valvulinera lenticula* (Reuss) recorded in Dubivtsi chalk as species that have an epifaunal mode of life, while *Praebulimina reussi* (Morrow), *Marssonella oxycona* (Reuss) and *Arenobulimina* sp. are species with an inferred infaunal life position. *Lenticulina* is regarded as a highly adaptable and tolerant species that may change habitats from epifaunal to infaunal in response to changing environmental conditions and food supply. We interpret it here as an epifaunal form. Foraminifers with an inferred epifaunal mode of life comprise more than 90% of benthic foraminiferal assemblages in the Dubivtsi chalk (Fig. 10).

Low abundance and diversity, dominated by calcareous epifaunal morphotypes, benthic foraminiferal assemblages in the Dubivtsi chalk indicate a well-oxygenated oligotrophic environment on the sea floor (e.g., Jorissen *et al.*, 1995; van der Zwaan *et al.*, 1999). The very low contribution of infaunal and agglutinated foraminifers, which thrive best in environments associated with relatively high organic matter flux (e.g., Bernhard, 1986), supports this interpretation.

The planktonic microfossil assemblages of the Dubivtsi chalk are dominated by pithonellids considered by Keupp (1987) as calcareous dinoflagellate cysts. Gale *et al.* (2000) recognized that the increased abundance of calcispheres in Upper Cretaceous sediments represents a reduction in water productivity, which co-occurs with decrease in the abundance of foraminifera. Thus, the pithonellid-rich carbonates from the Dubivtsi chalk can indicate oligotrophic surface waters and support our palaeoenvironmental interpretation based on planktonic and benthic foraminiferal assemblages. Moreover, our data agree with the idea that a predominance of pithonellid calcispheres coincident with a low abundance of foraminifera is a good indicator for reduced surface water productivity (Gale *et al.*, 2000). In the upper Turonian of the Western Ukraine, dinoflagellates occupied an ecological niche where other microorganisms (foraminifera) could not thrive probably because

of an insufficient amount of food. Dinoflagellates as opportunists can live in variable environmental conditions because of their cyst-producing strategy (calcispheres), which helps them survive in unfavourable environmental conditions. According to Hemleben *et al.* (1989) diatoms are a major part of the diet of many modern species of planktonic foraminifers, and we suppose that planktonic foraminifera and microorganisms producing pithonellids do not belong to the same food chain (*cf.* Peryt *et al.*, 2002).

The calcium carbonate content in the analysed rock samples amounts to almost 100%. This indicates that very little siliciclastic sediments have been supplied from the land into the basin even during the significant sea level drop. This, in turn confirms the idea of tectonic quiescence in the studied and adjacent areas until the middle Conianian when the Subhercynian phase of Alpine orogenesis triggered an uplift of the southeastern part of the Danish–Polish Trough and supplied a large amount of terrigenous material to the basin (Pasternak, 1959; Pasternak *et al.*, 1987; Walaszczyk, 1992). The very low level of regional tectonic activity and near absence of emerged areas during the late Turonian would mean that few nutrients were supplied from the land. Moreover, the regression and the related changes in oceanic circulation could be additionally responsible for the transport of a small amount of nutrients from the open ocean into the epicontinental basin. Consequently, the late Turonian basin in which the Dubivtsi chalk originated was highly oligotrophic, and this was probably a reason that the planktonic and benthic foraminiferal assemblages show unusually very low diversity and low abundance.

CONCLUSIONS

A combined micropalaeontological and stable isotope study of the Dubivtsi chalk in the Western Ukraine allowed us to determine its middle late Turonian age and to precisely correlate the Ukrainian strata with coeval rocks in Western Europe. In particular, one long-term and clearly distinguishable positive excursion of the isotope curve ($\delta^{13}\text{C}$) in the Dubivtsi chalk is equivalent to a widespread upper Turonian positive peak recorded the upper *S. neptuni* Zone in Western and Southern Europe named the Hyphantoceras Event or Hitch Wood Event. The $\delta^{18}\text{O}$ curve for the Dubivtsi chalk shows an increasing trend similar to other localities where the Hyphantoceras/Hitch Wood Event has been recorded.

Sedimentation of pure Dubivtsi chalk occurred under highly oligotrophic conditions, which is reflected in planktonic and benthic foraminiferal assemblages. Those conditions probably were triggered by regression and related changes in oceanic circulation and a low level of regional tectonic activity, which in consequence resulted in a very low supply of nutrients to the basin. The rise in abundance of pithonellid calcispheres coinciding with drop in the abundance of foraminifera can be a good indicator for reduction in surface water productivity.

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