

Planktic and benthic foraminiferal distribution patterns as a response to changes in surface fertility and ocean circulation: a case study from the Late Albian 'Amadeus Segment' (Central Italy)

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ABSTRACT – A combined geochemical and micropalaeontological study of the late Albian 'Amadeus Segment' of the Aptian–Albian organic-rich Scisti a Fucoidi Formation in central Italy shows that planktic foraminiferal assemblages record changes in abundance and composition which are markedly related to CaCO₃ and Total Organic Carbon content of the sediments. The distribution pattern of different genera seems to record changes in nutrient supply and surface water temperature. Changes in palaeoceanographic regime are also reflected in abundance, composition and trophic structure of benthic foraminiferal assemblages as a response to variations of oxygen content and organic flux to the sea floor. *J. Micropalaeontol.* 17(1): 87–96, April 1998.

INTRODUCTION

Modern planktic foraminifera display a distribution which is essentially shaped by environmental factors such as temperature and nutrient distribution, and organized in major water masses. Their mid-Cretaceous representatives have been used for palaeoclimatic and palaeoceanographic reconstruction (Hart & Bailey, 1979; Wonders, 1980; Caron & Homewood, 1983; Leckie, 1987; Premoli Silva *et al.*, 1989b; Premoli Silva & Sliter, 1994) in a period when global climate is considered to have been considerably warmer than the present ice-house state.

The present study aims to delineate the planktic and benthic foraminiferal distribution patterns from the late Albian 'Amadeus Segment' (Coccioni & Galeotti, 1993) of the Fiume Bosso section (Fig. 1) and to attempt a palaeoecological interpretation.

The Amadeus Segment, which belongs to the 'Whitish Marly Limestone Member' of the Scisti a Fucoidi Formation (Coccioni

et al., 1987, 1989) (Fig. 2), is dated to the planktic foraminiferal *Biticinella breggiensis* zone and *Ticinella praeticinensis* subzone. It consists of a rhythmic alternation of marls, calcareous marls and black shales. Two radiolarian-rich layers also occur.

Rhythmic Cretaceous sequences (e.g. the Aptian–Albian Scisti a Fucoidi) of the Umbria-Marche basin of central Italy have been studied by several authors (de Boer, 1982; Schwarzacher & Fischer, 1982; Fischer *et al.*, 1985, 1991; de Boer & Wonders, 1984; Herbert & Fischer, 1986; among others). De Boer (1982) and Herbert & Fischer (1986) suggested that the marl–limestone bedding couplets resulted from variations in carbonate supply and record a productivity cycle, in which the carbonate beds denote peaks and the shales lows in pelagic carbonate productivity. These authors determined that the marked lithologic alternation which characterizes Albian sediments of the Umbria-Marche basin is orbitally controlled. On the basis of

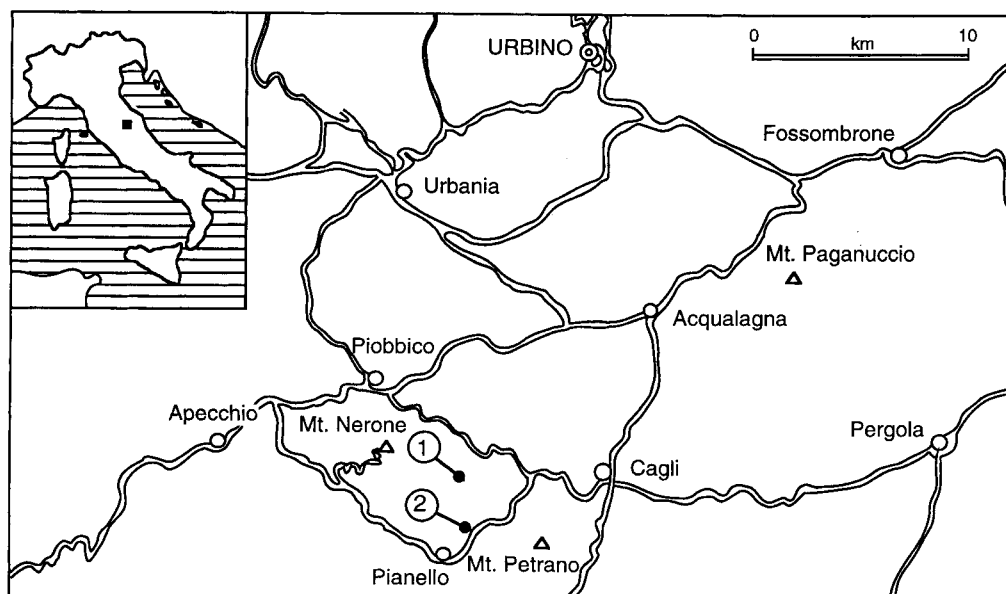


Fig. 1. Location of the Poggio le Guaine (1) and Fiume Bosso (2) sections which according to Coccioni *et al.* (1990a and b) are the reference sections for the Scisti a Fucoidi Formation in the Umbria-Marche Basin. The sections outcrop in the area of Geological Map of Italy, F. 290 'Cagli', 1:50,000.

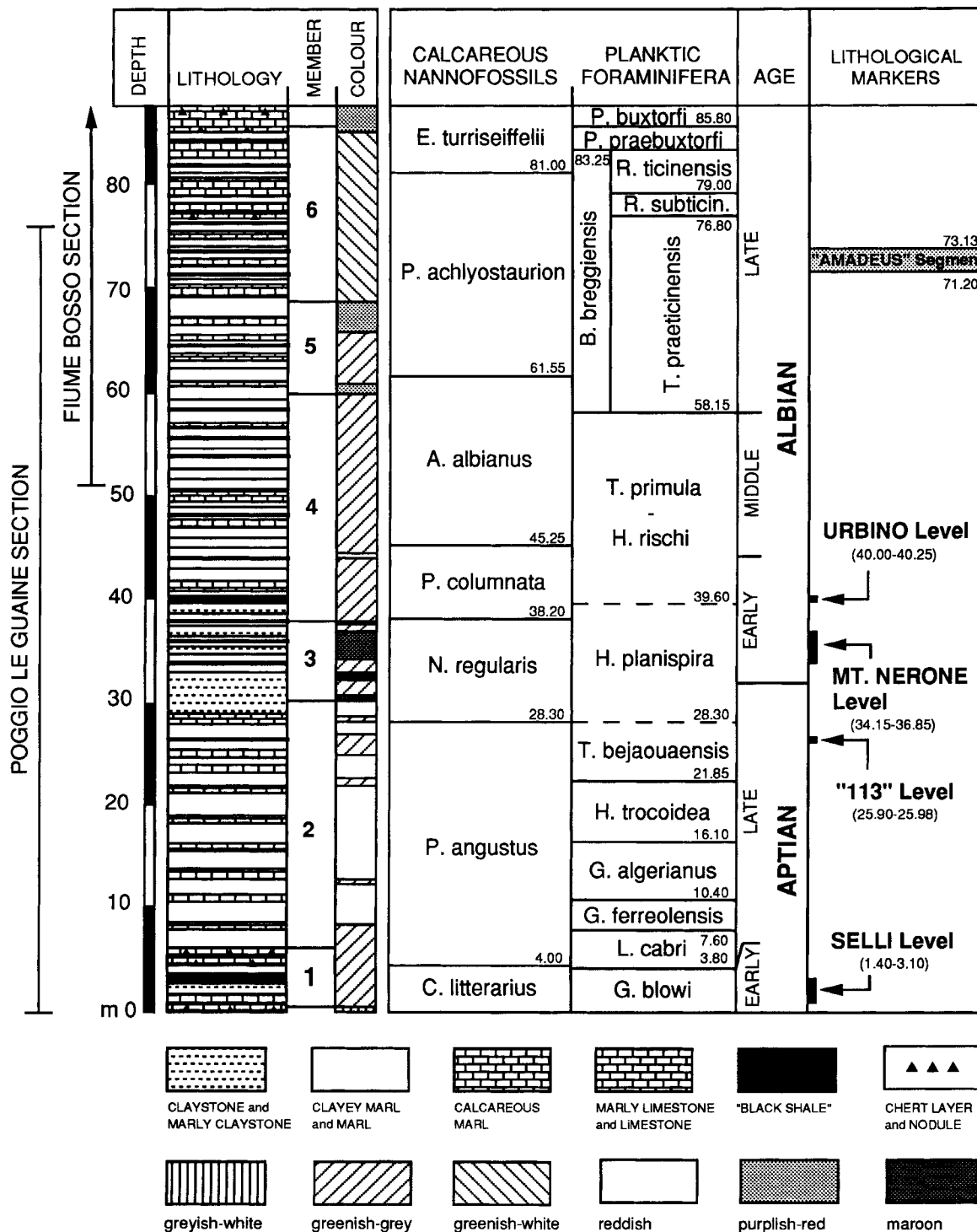


Fig. 2. Lithostratigraphy and biostratigraphy of the Poggio le Guaine-Fiume Bosso composite sequence (after Coccioni & Galeotti, 1993). Numbers indicate metres above the base. In the right column are reported the position of the Amadeus Segment and the position of four distinctive global and regional marker black-shales layers.

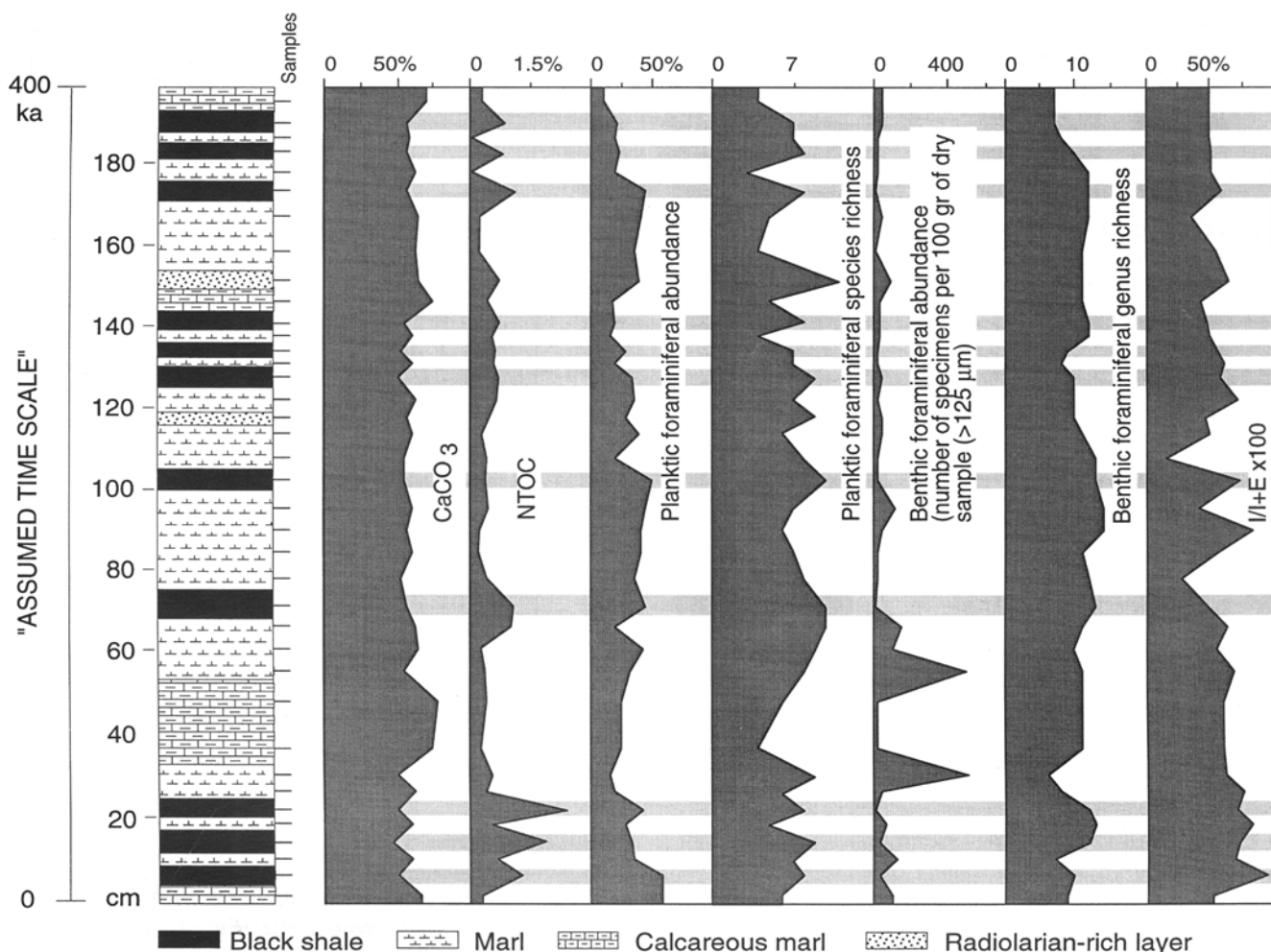


Fig. 3. Generalized lithological log of the Amadeus segment and variations of CaCO_3 content and faunal parameters. Abbreviations as follows: Ag = Agglutinated benthic foraminifera, CH = Calcareous-hyaline benthic foraminifera, I = Infaunal forms, E = Epifaunal forms.

isotopic data from the Moria section, de Boer & Wonders (1984) concluded that the carbonate highs of this portion of the Scisti a Fucoidi were deposited under cooler and more fertile waters. Changes in the abundance of planktic foraminifera and trace fossils distributions were interpreted as being orbitally controlled (Premoli Silva *et al.*, 1989a,b; Erba & Premoli Silva, 1994).

According to Coccioni & Galeotti (1993) the abundance, taxonomic composition, morphology, and test size of benthic foraminifera fluctuate greatly from layer to layer throughout the Amadeus Segment, therefore indicating that the orbital forcing markedly influenced the distribution of certain species, genera and morphogroups.

Because it provides an opportunity to integrate available data obtained from different proxies, the Amadeus Segment is ideal for evaluating at cm-scale the response of different genera and species of planktic foraminifera to cyclic fluctuations of the palaeoceanographic regimes.

MATERIAL AND METHODS

The Amadeus Segment was sampled bed by bed, and 38 samples were taken from a deep trench to eliminate surface contamina-

tion. The CaCO_3 content of each sample was estimated volumetrically with a Dietrich-Fruhling calcimeter. The Total Organic Carbon (TOC) content was estimated with a Netzsch Simultaneous Thermal Analyser STA 429 and then calculated on a basis free of CaCO_3 content to obtain a normalized value (NTOC). A constant terrigenous input can be assumed for the studied interval (Fischer & Herbert, 1986). Calculating the TOC value on a basis free of CaCO_3 content, would, therefore, avoid disturbance due to changes in sedimentation rate, allowing a better evaluation of organic matter fluxes and preservation on the sea-floor.

Sample preparation for foraminiferal study involved the crushing of 150 g of sediment sample and disaggregation with diluted hydrogen peroxide solution, washing through a $63 \mu\text{m}$ sieve and drying. The abundance of planktic foraminifera was estimated by counting identifiable organisms on a graduated screen and comparing obtained values with those from grain-size diagrams (Baccelle & Bosellini, 1965). A random portion of the washed residue was picked, yielding at least 300 specimens of planktic foraminifera from the fraction greater than $63 \mu\text{m}$. Planktic foraminiferal abundance and diversity (species rich-

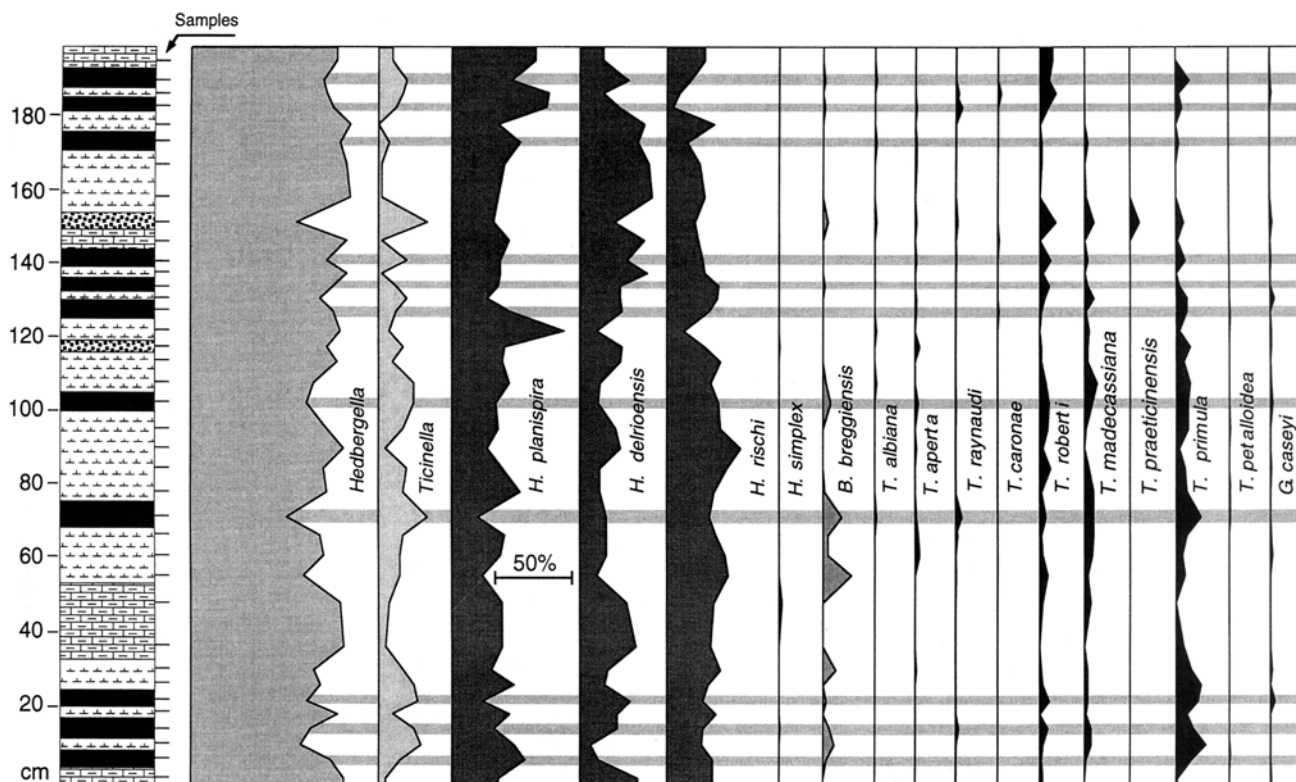


Fig. 4. Generalized lithological log of the Amadeus Segment and relative abundance percentages of planktic foraminiferal genera and species.

ness) were plotted against lithology, CaCO_3 content, NTOC, and the benthic foraminiferal faunal parameter records from Coccioni & Galeotti's (1993) data set (Fig. 3). The relative abundance of each genus and species was plotted against lithology (Fig. 4). Cross-correlation plots of planktic foraminiferal diversity and generic abundance, and CaCO_3 content were also calculated (Fig. 5).

On the basis of their chamber arrangement and inferred mode of life the benthic foraminifera were allocated into ten morphogroups following different authors (Jones & Charnock, 1985; Bernhard, 1986; Corliss & Chen, 1988; Koutsoukos & Hart, 1990).

The generic classification followed herein is mainly based on that outlined by Loeblich & Tappan (1987). Classification at species level is based on a wide range of literature. A list of the species cited in the text and used in the figures is given in the Appendix.

RESULTS

The CaCO_3 record of the Amadeus Segment ranges from 50 to 75% (Fig. 3), with minima of 50–55% in the black shales. The TOC content assumes values ranging from a minimum of 0.21% total weight (t.w.) in Sample 36 to a maximum of 3.1% t.w. in Sample 6; its average value is 0.4% t.w. in the carbonate highs to 1.5% t.w. in the black shales (Fig. 3).

Planktic and benthic foraminiferal assemblages record marked changes in abundance and in composition throughout the studied interval which are largely related to the CaCO_3 content of the sediment also reflecting the NTOC content (Figs 3 and 4).

Planktic foraminifera

Planktic foraminiferal assemblages are composed of 16 species belonging to four genera, among which *Hedbergella* and, subordinately, *Ticinella* predominate (Fig. 4). *Biticinella* and particularly *Globigerinelloides* occur discontinuously throughout the studied interval. Preservation is moderate to good.

As already shown by Premoli Silva *et al.* (1989a,b) the abundance of planktic foraminifera peaks at intermediate values of CaCO_3 content whereas it decreases in the carbonate highs assuming medium values in the black shale layers.

In addition, a peculiar distribution of planktic foraminiferal genera and species was recognized. When CaCO_3 content reaches the highest values, planktic foraminiferal content is very low and *Hedbergella* represents almost the entire assemblage with a maximum relative percentage in abundance of 98%. By contrast, the relative abundance of *Ticinella* and *Biticinella breggiensis* peaks at low values of CaCO_3 content (Figs 4 and 5). The discontinuous distribution of *Globigerinelloides caseyi* does not enable a thorough evaluation. However, it must be noted that *G. caseyi* is absent when CaCO_3 content reaches values higher than 65%.

Fluctuations in relative abundance of different species of *Hedbergella* do not parallel the record of the genus to which they belong. Conversely, *Ticinella madecassiana*, *T. primula*, and *T. roberti*, which have a continuous distribution in contrast to other species of *Ticinella*, display variations in relative abundance that parallel the record of the genus, and covary with the CaCO_3 content and NTOC. In fact they become more abundant in the marly portions of the Amadeus Segment where the black shale/marl couplets are clearly recognizable (i.e. the marly

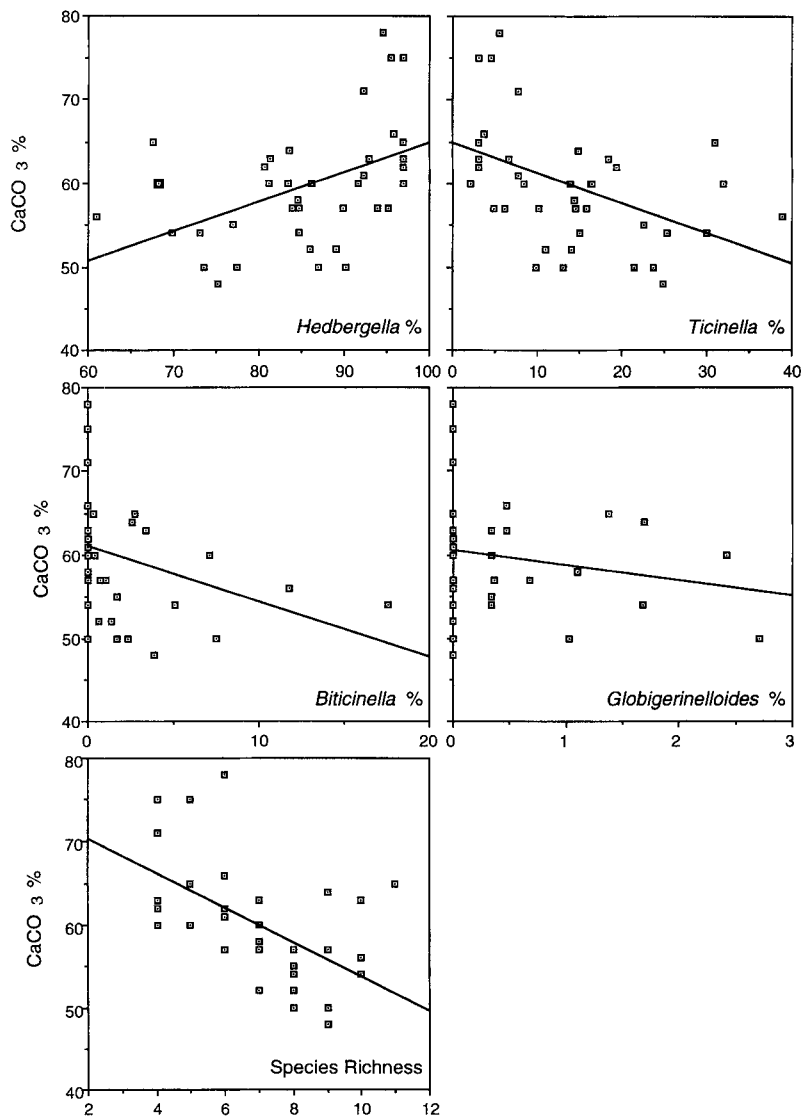


Fig. 5. Cross correlation scattergrams of planktic foraminiferal genera relative abundance and species richness, and CaCO₃ content of the sediments. High CaCO₃ content would be related, according to de Boer (1982) and Herbert & Fischer (1986), to periods of maximal productivity.

portion of the bundles of Herbert & Fischer, 1986).

The species richness also shows a correspondence with lithology reaching the highest values with low values of CaCO₃ and high values of NTOC (Figs 4 and 5). Its maximum value has been recorded in a marly layer (Sample 30) which is, however, characterized by a rather low CaCO₃ percentage and a NTOC content which is double the average from the carbonate highs.

Benthic foraminifera

Benthic foraminiferal assemblages are composed of calcareous hyaline and both calcareous and siliceous agglutinating forms. Preservation is moderate to good. Forty-two species were identified belonging to 22 genera among which *Gyroidinoides*,

Arenobulimina, *Dorothia*, and *Clavulinoides* predominate.

The benthic foraminiferal assemblages change with lithology (Fig. 6) and three distinct associations can be recognized (see Fig. 9 for details).

According to Coccioni & Galeotti (1993) these changes in benthic foraminiferal assemblages abundance and composition are related to the response of benthic foraminiferal communities to fluctuations of nutrient flux and the oxygen content at the sea-bottom, as well as the sedimentation rate.

Moreover, the distribution of many species, genera and morphogroups appears to be cyclic (Figs 6 and 7). However, some of them (e.g. *Marssonella oxycona*, *Pleurostomella*, and branching morphotypes) exhibit a discontinuous distribution that it is very difficult to interpret.

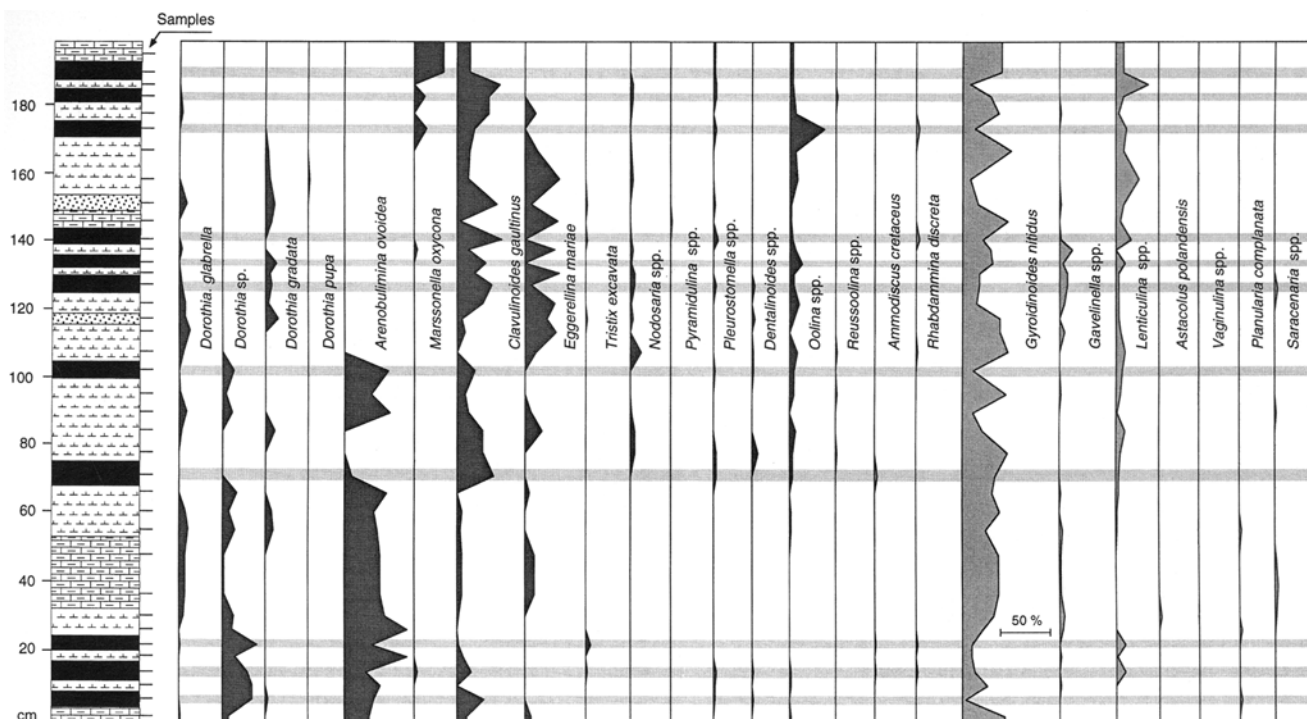


Fig. 6. Generalized lithological log of the Amadeus Segment and relative abundance percentages of benthic foraminiferal genera and species. Dark stippled = infaunal forms, light stippled epifaunal forms

DISCUSSION

Fischer & Herbert (1986) studied an 8 m core segment from the Upper Albian portion of the Scisti a Fucoidi containing the Segment-1 of Premoli Silva *et al.* (1989) which in turn is litho- and bio-stratigraphically correlatable to the Amadeus Segment, suggesting that the lithologic alternation is related to Milankovitch cycles.

According to these authors, bedding couplets reflect the precession, bundles record the short eccentricity cycles, and dissolution effects did not play an important role in determining the alternation of marl–limestone beds. Moreover, the very good state of preservation of planktic foraminifera in the black shale layers suggests that the sequence was not notably affected by carbonate migration. This is one of the reasons why Herbert & Fischer (1986) interpreted lithologic cycles from the late Albian Scisti a Fucoidi as chiefly due to cyclical changes in carbonate productivity and sea-floor stagnation. Variations in detrital supply, oscillations in carbonate dissolution, and episodic winnowing have, in fact, to be excluded as the cause of the lithological cycles (Fischer & Herbert, 1986; Herbert & Fischer, 1986). Moreover, Erba (1992) suggested a minor effect of diagenesis on nannofossil assemblages from the Amadeus Segment. The latter author also noticed that species diversity among nannofossil assemblages is higher during carbonate lows.

Any relation between the CaCO_3 and NTOC content and planktic foraminiferal distribution pattern has, therefore, to be seen in terms of a response of these organisms to orbital perturbation capable of triggering changes in the upper water column structure and nutrient supply. In particular, the carbonate-rich layers, where the highest abundances of *Hedbergella*

occur, indicate periods of high fertility and a strong mixing of the surface waters. The shaly intervals, where *Ticinella* and *Biticinella breggiensis* display relative abundance peaks, would represent, according to Premoli Silva *et al.* (1989a,b), periods of lower productivity and greater water stratification. Accordingly, *Hedbergella* thrived under eutrophic conditions, whereas more oligotrophic conditions favoured *Ticinella* and *Biticinella* (Figs 8 and 9). Coccioni *et al.* (1992) suggested that *Globigerinelloides* preferred mesotrophic conditions, which seems to be likely as *G. caseyi* is absent when the CaCO_3 content is higher than 65%. According to Caron & Homewood (1983) planktic foraminiferal forms such as *Hedbergella* living in the shallowest waters are favoured during periods of lower temperature and overall environmental instability, whereas *Ticinella* and *Biticinella* which are inferred to live at greater depths (Leckie, 1987) should thrive under conditions of environmental stability.

Changes in water temperature might have played a fundamental role in controlling the abundance and composition of depth-stratified planktic foraminiferal assemblages, as well as inducing changes in water structure, depth of the thermocline, water density and salinity. Leary *et al.* (1989) documented peak abundances of hedbergellids from the Cenomanian of southern England associated with higher temperature of surface waters as indicated by isotopic evidence. Br  heret *et al.* (1985) reported important changes in the planktic foraminiferal assemblage composition related to both lithologic and geochemical variations across the organic-rich early Albian Paquier level in the Vocontian Basin where high abundances of small-sized hedbergellids occur. The latter authors suggested that deeper dweller ticinellids were affected by an expansion of the oxygen minimum

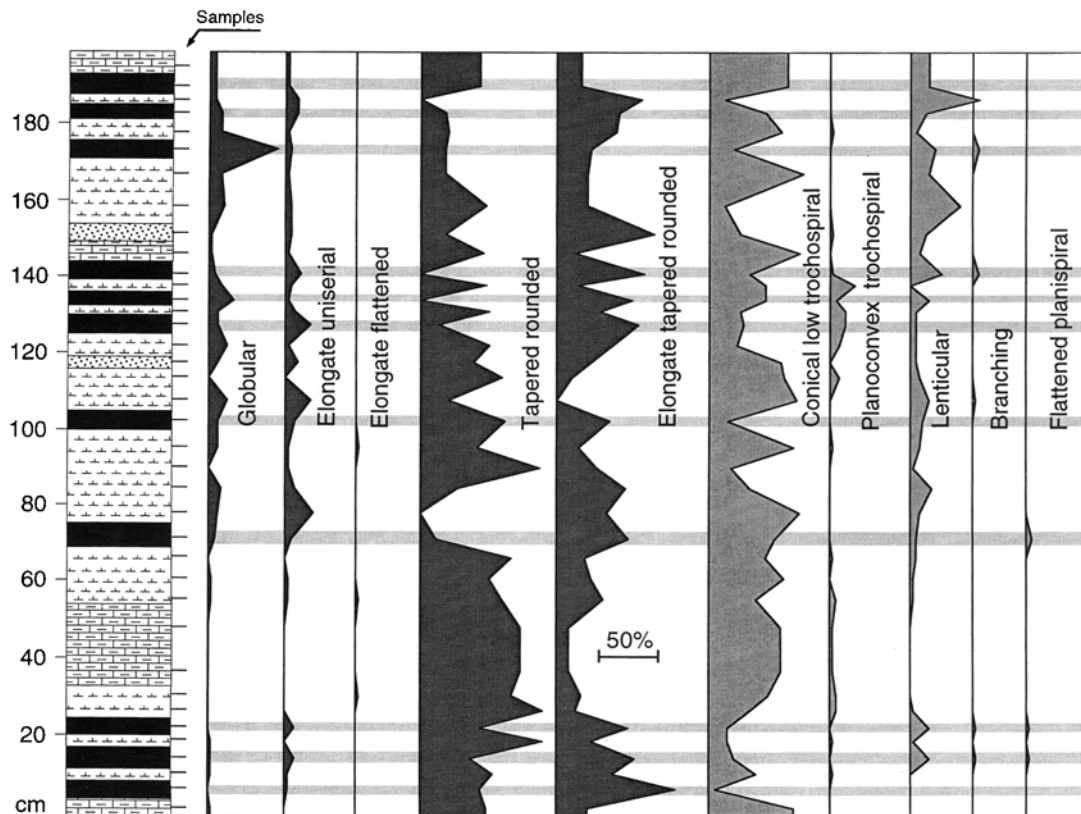


Fig. 7. Generalized lithological log of the Amadeus Segment and relative abundance percentages of benthic foraminiferal morphogroups. Dark stippled = infaunal forms, light stippled epifaunal forms.

zone during periods of higher surface fertility and organic-rich horizon deposition.

Conversely, the peak abundances of *Hedbergella* in the Amadeus Segment occur within the calcareous marly layers which, according to de Boer & Wonders (1984), were deposited during periods of lower surface water temperatures. It seems then likely that rather than temperature nutrient availability was a limiting factor controlling the abundance of opportunistic taxa (*r*-selected) such as *Hedbergella*. Temperature might have been, indeed, the most important factor in controlling the distribution of *K*-selected taxa such as *Ticinella* and *Biticinella*, which thrived during warmer periods when the thermocline should have been deeper, allowing the development of ecological niches available for deeper dwellers. Different species of *Hedbergella* seem instead to be less sensitive to variations of the thermocline position possibly because they occupied ecological niches very close to the sea-surface.

Interestingly, the conditions which favour the opportunistic *r*-selected planktic foraminifera tend to make the benthic foraminiferal assemblages *K*-selected as reported in Fig. 9. Conversely, during the deposition of the black shale layers when the *K*-selected tinellids are favoured, benthic foraminiferal assemblages become *r*-selected and characterized by high dominance and predominance of small-sized specimens (Fig. 9). This trend comes as a surprise because in deep ocean settings the benthic fauna is entirely dependent on the flux of organic matter from the surface ocean for food.

It is usually difficult to interpret what chiefly contributes to the breaking of normal recycling of carbon into the ocean. Reduction in ocean circulation and increased marine primary production are, in fact, interdependent parameters. The problem is further complicated by other parameters such as the benthic release of reactive phosphorus available for primary producers which in turn seems to be related to oxygen content at the water sediment interface (Van Cappellen & Ingall, 1994).

In the case of the Amadeus Segment, there is evidence of greater accumulation of organic matter during periods of lower fertility which results in a 'reversed' coupling between planktic and benthic foraminiferal assemblages. This can be explained only by a depletion of dissolved oxygen at the sea-floor as well as in the water column which enhanced both export rates and preservation of organic matter resulting in the deposition of the black shales. A possible decrease of downward flux of oxygen due to water stratification would have favoured the development of dysaerobic conditions allowing higher particulate fluxes to escape the surface water column during periods of lower primary productivity and lower seasonality. Contrarily, the lithotypes richer in organic matter would have deposited during periods of higher fertility. The possibility that higher concentrations of organic carbon within the black shales are mainly associated with changes in the sedimentation rate has to be excluded. The TOC records highs in the black shales even with CaCO_3 free values (NTOC).

Understanding which mechanisms are responsible for the

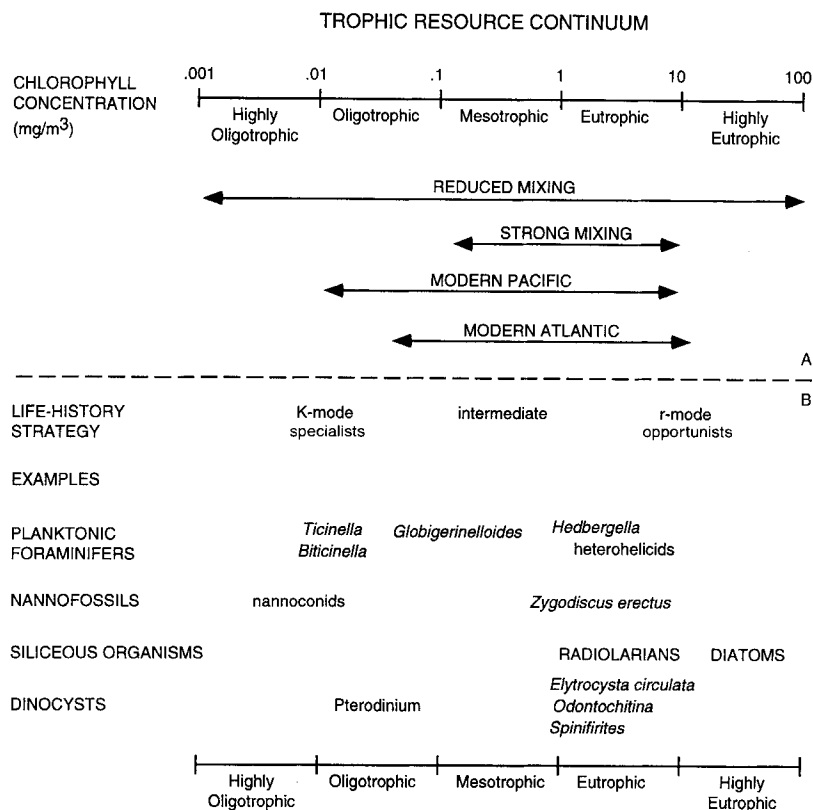


Fig. 8. Comparison of modern oceanic conditions (A) and those inferred for the Lower Cretaceous (B). After Hallock (1987) and Coccioni *et al.* (1993).

coupling between planktic and benthic foraminiferal assemblages is a crucial point to improve our knowledge of the palaeoceanographic conditions leading to organic carbon-rich facies.

CONCLUSIONS

Abundance, taxonomic composition, and diversity of planktic and benthic foraminiferal assemblages fluctuate markedly throughout the Amadeus Segment as a consequence of the change in fertility of surface waters and palaeoceanographic regime.

A relationship between lithology, NTOC, and planktic foraminiferal distribution patterns is recognizable, and variations in the relative abundance of different taxa are strongly related to changes in the nutrient supply and upper water column structure. In particular, *Hedbergella* indicates a more eutrophic habitat, whereas *Ticinella* and *Biticinella* preferred more oligotrophic conditions. *Globigerinelloides* would be an indicator of mesotrophic conditions. However, different species of *Hedbergella* emerge as poor palaeoecologic indicators as their record does not parallel the record of the genus to which they belong. Nutrient availability was the main limiting factor for *Hedbergella*, whereas *Ticinella* and *Biticinella* seem to be more sensitive to variations in temperature.

The response of benthic foraminifera to these fluctuations in the surface environment indicates a close coupling between the

surface and bottom ecosystems, as the alternation of low and high primary productivity regimes resulted in rapid changes in the trophic structures of benthic foraminiferal assemblages which, according to Coccioni & Galeotti (1993), are orbitally controlled. The preservation of a larger amount of organic matter during the deposition of black shales was apparently caused by oxygen depletion which allowed higher organic fluxes to the sea-floor rather than by higher primary productivity and/or changes of sedimentation rate.

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APPENDIX: Species list arranged in taxonomic order following Loeblich & Tappan (1987)

Planktic foraminifera

Hedbergella delrioensis (Carsey, 1926)

Hedbergella planispira (Tappan, 1940)

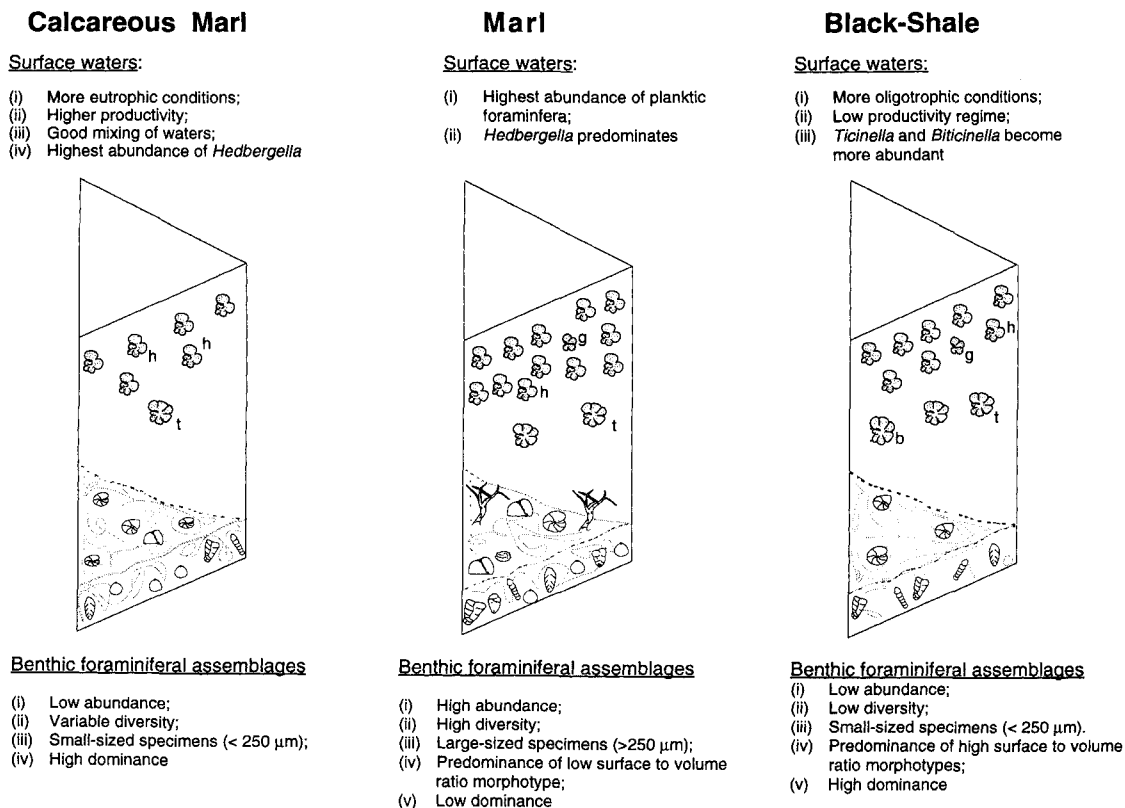


Fig. 9. Amadeus Segment – Idealized palaeoenvironmental reconstruction of the sea-floor related to different lithology and surface waters conditions. As regards planktic foraminifera *Hedbergella* and *Globigerinelloides* (labelled as h and g respectively) are placed in the uppermost water column whereas *Ticinella* and *Biticinella* (labelled as t and b, respectively) are placed in deeper positions. As concerns benthic foraminifera, the inferred life-position within or onto the sea floor is according to the morphogroup organisation described in the text (see also Coccioni & Galeotti, 1993).

- Hedbergella rischi* Moullade, 1974
- Hedbergella simplex* (Morrow, 1934)
- Biticinella breggiensis* (Gandolfi, 1942)
- Ticinella albiana* Longoria & Gamper, 1977
- Ticinella aperta* Sigal, 1966
- Ticinella caronae* Longoria & Gamper, 1977
- Ticinella madecassiana* Sigal, 1966
- Ticinella petalloidea* Longoria & Gamper, 1977
- Ticinella praeticinaensis* Sigal, 1966
- Ticinella primula* Luterbacher & Premoli Silva, 1962
- Ticinella ex gr. raynaudi* Sigal, 1966
- Ticinella roberti* (Gandolfi, 1942)
- Globigerinelloides caseyi* (Bolli, Loeblich & Tappan, 1957)

Benthic foraminifera

- Rhabdammina ex gr. discreta* Brady, 1881
- Ammodiscus cretaceus* (Reuss, 1862)
- Eggerellina mariae* Ten Dam, 1950
- Arenobulimina ovoidea* Marie, 1941
- Dorothia glabella* Cushman, 1933
- Dorothia gradata* Berthelin, 1880
- Dorothia pupa* (Reuss, 1860)
- Marssonella oxycona* Reuss, 1860
- Clavulinoides gaultinus* (Morozova, 1948)

- Tristix excavata* (Reuss, 1863)
- Astacolus polandensis* Trujillo, 1960
- Planularia complanata* (Reuss, 1845)
- Gyroldinoides nitidus* (Reuss, 1846)

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