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Coiling direction in *Globigerina bulloides* of Middle Miocene age

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ABSTRACT – Detailed analysis of the early evolutionary stage of *Globigerina bulloides* in Middle Miocene calcareous nannoplankton zones NN5 and NN6 shows no preference for sinistral or dextral coiling patterns despite seawater temperature variations (as inferred from stable isotope analyses of foraminifer shells). Accordingly, coiling direction was proportional or biased to sinistral. *J. Micropalaeontol.* **22**(2): 141–146, November 2003.

INTRODUCTION

The coiling direction is an easily measured morphological variable exhibited by planktonic foraminifera. The feature was first applied to studies of the evolution of planktonic foraminifera by Bolli (1950, 1951) who discovered that species often coil equally sinistrally and dextrally when they first appear in the geological column and later exhibit one of four preferential coiling patterns (Fig. 1). Distinct oscillations in coiling preference can occur within a single species (Bolli, 1971; Bolli *et al.*, 1985). Winter & Pearson (2001) have suggested that long-term coiling trends in some species appear to be global and genetically controlled.

It has been suggested that recent populations of *Globigerina bulloides* exhibit a relationship between coiling direction and seawater temperature: in warmer waters dextral forms prevail (e.g. Boltovskoy, 1973; Malmgren & Kennett, 1977). *G. bulloides* is very common in the Middle Miocene (Badenian) of Paratethys and it has been possible to perform a detailed analysis of specimens at an early evolutionary stage of this species which appeared in the Late Langhian (Kennett & Srinivasan, 1983).

MATERIAL AND METHODS

The studied samples come from an original environment in the Central Paratethys. The Middle Miocene deposits (mostly siltstones with limestone intercalations) have been studied in boreholes located near Gliwice (Upper Silesia, Poland). These sediments originated in a marine basin situated to the north of the Carpathian orogen.

The studied sections represent the entire Badenian sequence (see Gonera *et al.*, 2000). *Orbulina suturalis*, the index taxon of the Middle Miocene zone N9 (Blow, 1969), occurs at the base of the studied sections. This occurrence indicates that our samples are not older than zone N9 (Gonera, 1997). Other planktonic foraminifera present in the sections are *Streptochilus globigerum*, *Globorotalia praescitula*, *Globorotalia acrostoma*, *Globorotalia mayeri*, *Neogloboquadrina continuosa*, *Dentoglobigerina altispira*, *Globoquadrina dehiscens*, *Globoquadrina venezuelana*, *Velapertina indigena*, *Cassigerinella chipolensis*, *Globigerina bulloides* (Plate 1), *Globigerina angustiumbilicata*, *Globigerina concinna*, *Globigerina decoraperta*, *Globigerina diplostoma*, *Globigerina druryi*, *Globigerina woodi*, *Globigerinita uvula*, *Globigerinella obesa*, *Globigerinella praesiphonifera*, *Globigerinoides quadrilobatus*, *Turborotalita quinqueloba*, *Orbulina bilobata* and *Praeorbulina glomerosa*. Accordingly, there is lack of taxa (e.g. *Foshella* group) indicating biozones younger than N9. Calcareous nannoplankton assemblages represent two zones (Peryt, 1997): *Sphenolithus heteromorphus* (NN5) and *Discoaster exilis* (NN6). Based on these data the age of the studied deposits is regarded as Late Langhian and Serravallian (in part).

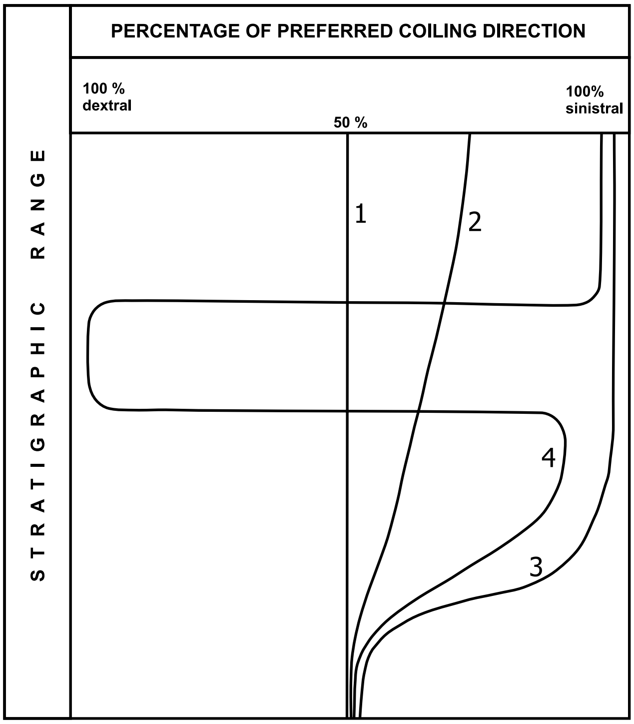


Fig. 1. Four principal coiling trends in planktonic foraminifera after initial random stage (after Bolli, 1971). Pattern 1 – no clear preference; pattern 2 – moderate preference for one direction, which may be just over 50% or more; pattern 3 – rapid change to an almost exclusively preferred direction, to be maintained during subsequent evolution; pattern 4 – a distinctly preferred direction, but with alternation(s) to the opposite direction.

Samples containing several hundred specimens of *Globigerina bulloides* have been selected for the study and, in addition, the selected samples included all foraminiferal zones recognized in the Badenian (Gonera, 2001). Altogether 62 samples from eight boreholes have been analysed. The coiling direction of

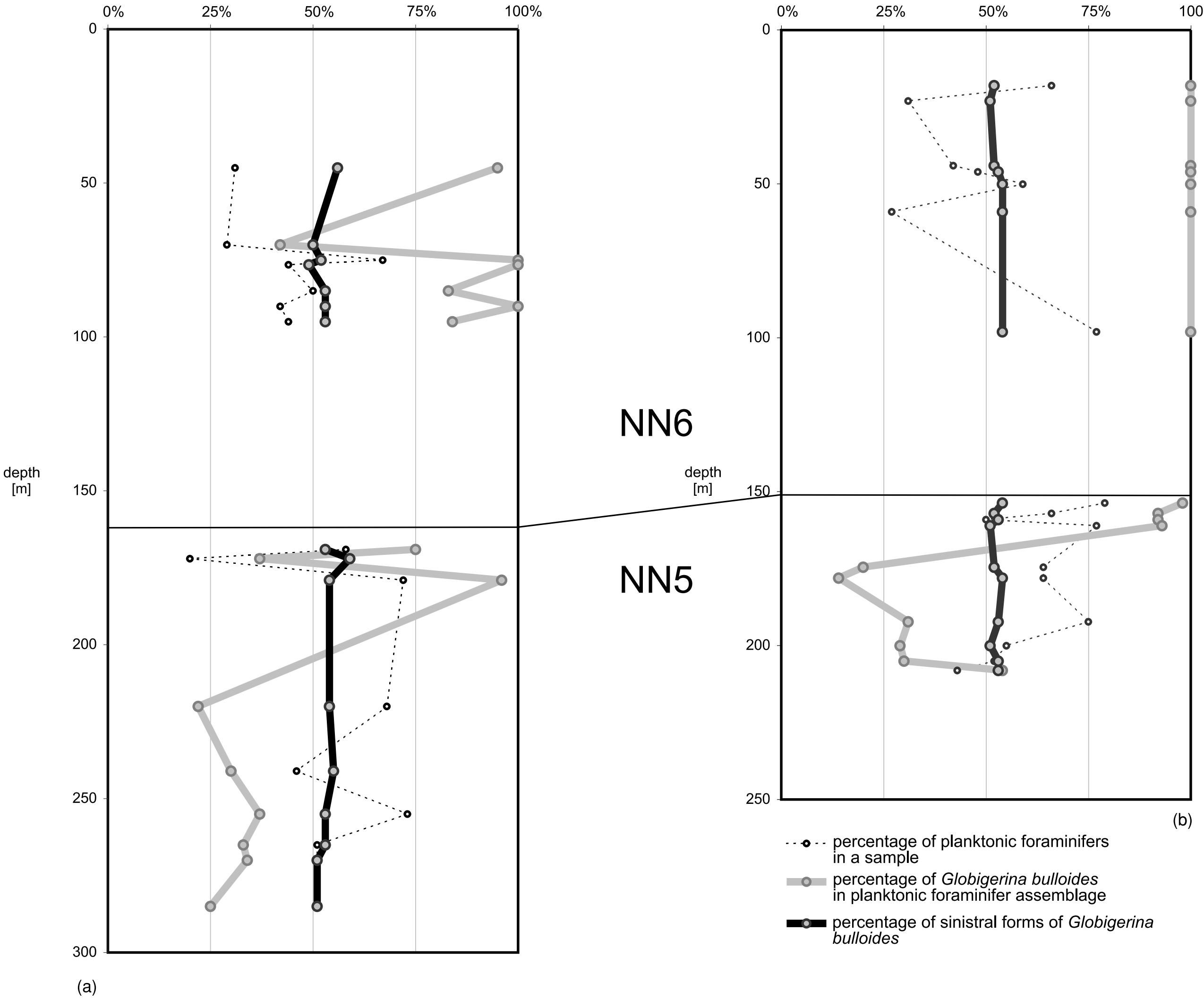


Fig. 2. Coiling direction of *Globigerina bulloides* in (**a**) the Gliwice 19 and (**b**) Gliwice 24 sections.

G. bulloides tests has been studied in the 125–430 µm fraction (in this fraction adult specimens occur). The number of observed *G. bulloides* specimens ranges from 332 to 815 and mostly it was 500–600 specimens per sample. Altogether the coiling direction was determined in 33 000 tests. The foraminifera studied are well preserved (see Plate 1).

RESULTS

The percentage of *Globigerina bulloides* sinistral ranges from 48.6 to 58.7. Most of the samples contain 50–54% of sinistral specimens (Figs 2a, b). The ratio of sinistral forms was calculated for particular foraminiferal zones (Fig. 3) and it was found that the measured values are very similar in all those zones despite a great variation of percentage of planktonic foraminifera in a sample and the relative abundance of *G. bulloides* in foraminiferal assemblages. The ratio of sinistral tests remained stable throughout the considered time span (Late Langhian–Serravallian) and the values of standard deviation (Fig. 3) are very low.

DISCUSSION

Recently a cryptic species status has been proposed for genotypes of a number of recent planktic foraminifer species (Darling *et al*., 1999). The discoveries on molecular genetics in planktonic foraminifera indicate the necessity for reassessment of species concepts for the group (Darling *et al*., 2000). They also indicated that modern *Globigerina bulloides* consists of at least five cryptic species (Darling *et al*., 2000). However, it is not concluded yet whether genotypic variants can be distinguished on the basis of the test morphology (Stewart *et al*., 2001), which is very important for many ancient cases. More study is needed to determine how much the cryptic species of any morphospecies differ in regard to the inhabited environment. The measured coiling direction refers to specimens of the morphological taxon *G. bulloides* d'Orbigny in its traditional meaning (Kroon & Darling, 1995; Norris & Nishi, 2001).

Recently it has been suggested that evolutionary changes imply genetic control of coiling direction (Norris & Nishi, 2001; Winter & Pearson, 2001) but, on the other hand, the coiling of young *Amphistegina* is independent of coiling direction of the

AGE AND CORRELATION WITH OXYGEN ISOTOPE STRATIGRAPHY (Miller et al., 1991; Gonera, 2001)		BIOSTRATIGRAPHY		STATISTICAL DATA					NUMBER OF STUDIED SAMPLES
		FORAMINIFER ZONES (Gonera, 1997)	CALCAREOUS NANNOPLANKTON ZONES (Peryt, 1997)	MINIMAL	MAXIMUM	AVERAGE	DEVIATION	MEDIAN	
SERRAVALLIAN	**Mi5** ↗	IIIB	NN6 (pars)	49.0	55.6	52.2	1.5	52.0	**26**
		IIIA-α		49.0	54.2	50.9	1.5	51.1	**10**
	Mi4 →	IID	NN5 (pars)	49.6	58.7	52.6	3.1	51.9	**7**
	Mi3 →	IIC		48.6	51.3	50.3	1.5	51.0	**3**
LANGHIAN		IIβ		50.9	53.6	52.5	1.4	52.9	**3**
		IIA-B		50.7	55.1	52.7	1.3	53.0	**13**

Fig. 3. Percentage of *Globigerina bulloides* sinistral forms in particular Badenian biozones.

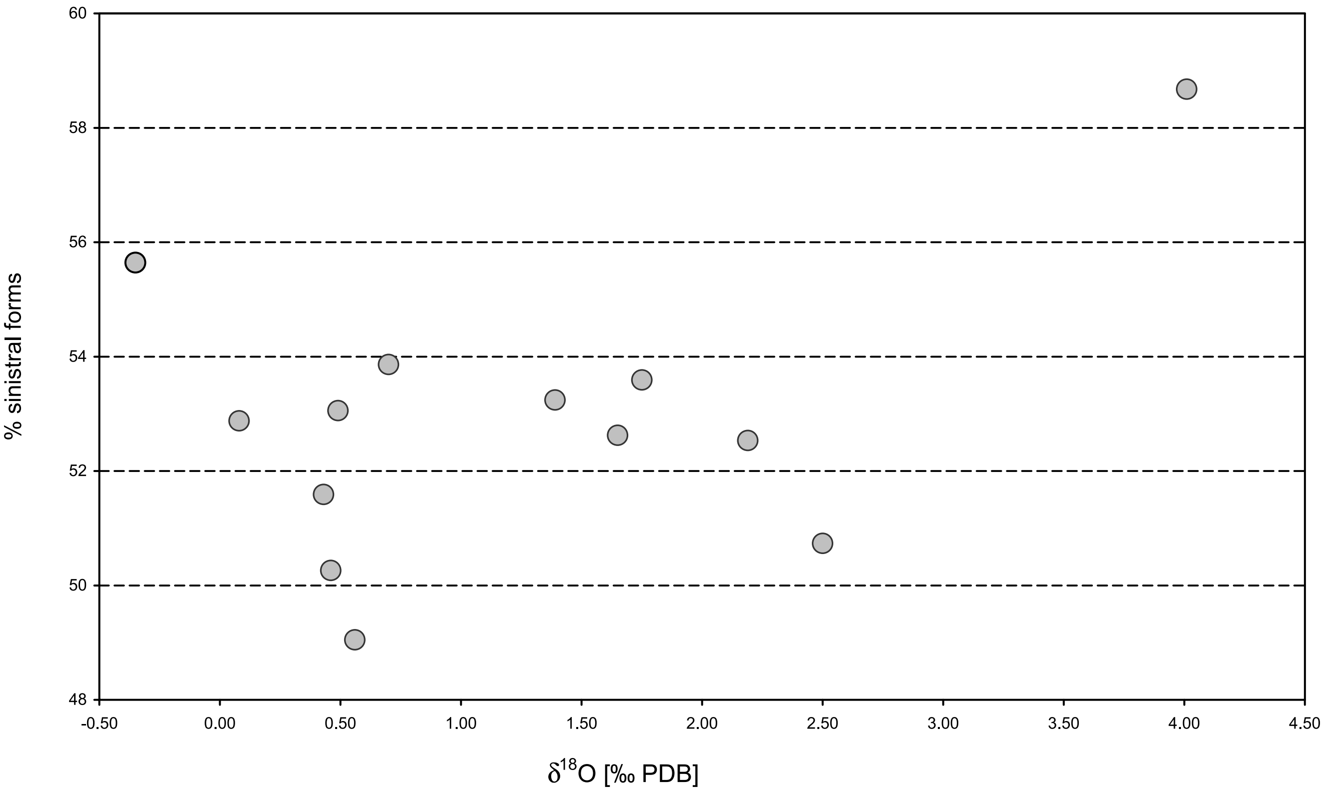
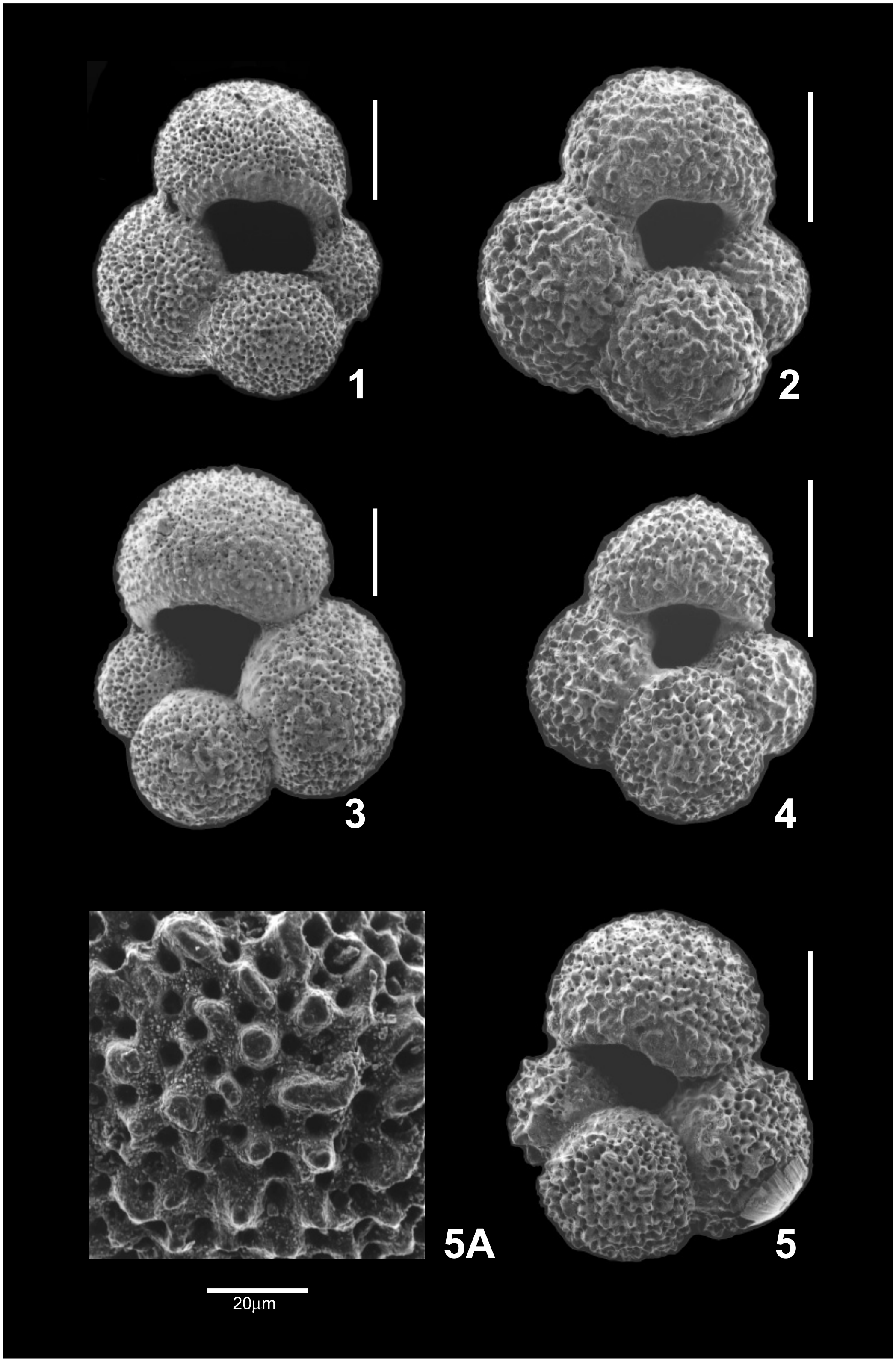


Fig. 4. Percentages of *Globigerina bulloides* sinistral forms versus $\delta^{18}O$ values of their tests in the studied samples from the Gliwice 19 borehole.

parent individual (Hallock & Larsen, 1979) and this is difficult to explain genetically. Consequently, coiling direction can be controlled by biochemical processes in the genes, but it is also environmentally influenced, the temperature being the most important environmental factor (Bandy, 1960; Hallock & Larsen, 1979). Naidu & Malmgren (1996) suggested that water temperatures may not be the only factor controlling coiling direction. Fossil populations of *Neogloboquadrina pachyderma* and *G. bulloides* studied by them display enhanced flux of the sinistral morphotypes during intensive upwelling conditions



Explanation of Plate 1. *Globigerina bulloides*: **fig. 1.** Gliwice 19, depth 90.0 m; **fig. 2.** Gliwice 24, depth 178.0 m; **fig. 3.** Wilcza 1, depth 40.5 m; **fig. 4.** Pilchowice 10, depth 520.0 m; **fig. 5.** Sumina 2, depth 294.0 m; **fig. 5A.** enlargement of surface of specimen in 5. Scale bars, 100 μm (except 5A).

and, thus, the nutrient level seems to play an important role (Little *et al*., 1997). Accordingly, the problem of whether the coiling direction is genetically, evolutionary or environmentally controlled remains enigmatic.

In the studied material, the average abundance of the sinistral forms of *Globigerina bulloides* is 50.3–52.7% (Fig. 3). Six samples (of the 62 studied) contained less than half (48.6–49.6%) in the sinistral form, and the dextral forms slightly prevailed in those samples. In most of the samples, however, sinistral forms predominate and their average percentage is 50.3–58.7%. It is difficult to decide whether the coiling was random or biased. The latter possibility is suggested by the fact that recent *G. bulloides* are sinistral. The abundance of sinistral forms in modern biocenoses of *G. bulloides* may be related to temperature (Bandy, 1972; Boltovskoy, 1973; Malmgren & Kennett, 1976). The modern populations of *G. bulloides* in cooler water masses (<4°C) show 80–100% of forms to be sinistral and, in the temperature range 4–15°C, the content of sinistral forms is 60–80%. In warmer waters the sinistral specimens of *G. bulloides* constitute 55–57% of the population.

$\delta^{18}O$ values of the studied populations of *Globigerina bulloides* show a large variation (Durakiewicz *et al*., 1997) (Fig. 4). The recorded $\delta^{18}O$ values of +2.50‰ PDB and −0.35‰ PDB correspond to the temperature change within 6–18°C, respectively (Fig. 4). No correlation can be traced between $\delta^{18}O$ values and the percentage of sinistral forms of *G. bulloides* (Fig. 4) and, thus, the coiling direction of *G. bulloides* in the Paratethys does not seem to be related to inferred temperature changes.

CONCLUSIONS

Analysis of coiling direction in the Middle Miocene (NN5–NN6 zones) populations of *Globigerina bulloides* suggests that at the early evolutionary stage of the species there was no differentiation into sinistral or dextral domination of coiling despite significant temperature changes in the studied cores, as indicated by the measured $\delta^{18}O$ values of *G. bulloides*. Our data and data on recent coiling direction indicate that the coiling pattern of *G. bulloides* shows pattern 2 of Bolli (1971). In addition, the data support the conclusion of Brunner & Kroon (1988) that 'proportionate coiling has persisted in most members of globigerinid clad throughout the Neogene' (Norris & Nishi, 2001, p. 341).

Recent populations of *G. bulloides* are characterized by the predominance of sinistral forms. Their content correlates with temperature and it attains the maximum value in cool waters, but even in the warmest waters it exceeds 55%. It was not the case in the studied Langhian–Serravalian populations when the early evolution of coiling direction was proportional or biased to sinistral. This feature persisted throughout the entire time interval and it did not depend on water temperature (as expressed by $\delta^{18}O$ values of foraminifer tests).

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