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Pliocene–Quaternary Biostratigraphy and Planktonic Foraminifera Evolution in the North Pacific

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Abstract—In analysis of the stratigraphic distribution of planktonic foraminifers in the Pliocene–Lower Quaternary sediments of the North Pacific, and research of the space-time distribution dynamics of 60 species at four levels corresponding to the foraminiferal zones N 19, N 20, N 21, and N 22 revealed, significant evolutionary changes at that time were revealed. Twenty-five species became extinct and ten species appeared. Since the early Pliocene, the foraminifer diversity decreased from 53 to 34 species. Three groups of species were revealed: (1) short-lived species; (2) species who reduced and extended distribution areas and abundances, and (3) species whose distribution patterns remained relatively stable. It was shown that the reduction of distribution areas proceeded from the periphery toward the center (i.e., toward the areas with the highest abundances) and, in contrast, distribution areas of the newly appearing and evolving species expanded from their center toward the periphery.

Key words: *planktonic foraminifers, Pliocene–Quaternary sediments, biostratigraphic distribution, datum plane, distribution areas, diversity, biogeographic provinces, extinction, evolutionary origin.*

INTRODUCTION

The study of distribution patterns of planktonic foraminifer species in oceanic sediments is the first important step in elaborating various biostratigraphic scales and defining paleoceanographic changes. Planktonic foraminifers provide a unique opportunity to carry out these investigations because of the fast evolutionary changes in this group of microorganisms during relatively short time intervals, dependence of their distribution on climatic zonality in the oceans, and sensitivity to the environments in surficial waters (Barash, 1988).

Recently, the stratigraphic subdivision of the Pliocene–Quaternary sediments of the World Ocean based on planktonic foraminifers was well substantiated: many levels of species extinction and appearance (datum planes) and other events in microplankton evolution were established. Based on these events, the criteria for defining boundaries of biozones and other stratigraphic units were elaborated. About 40 datum planes in the Pliocene–Quaternary sediments of the World Ocean are noted in many publications (Saito, 1977; Thompson and Sciarillo, 1978; Berggren, 1984). Still, the position of these datum planes in the particular sections can depend on local climatic and facies peculiarities, while not necessary coinciding with the level of the real evolutionary appearance or extinction of species (Dowsett, 1988; and others). This renders detailed biostratigraphic studies on the evolution of planktonic foraminifers in particular oceanic areas and regional peculiarities in the stratigraphic distribution of various species necessary. Several summarizing works were

dedicated to the stratigraphic aspects of foraminifer distribution in the Neogene–Quaternary sediments of the Pacific (Parker, 1967; Kennett and Srinivasan, 1984; Bolli and Saunders, 1985). In many publications, special attention was paid to the problems of evolutionary changes in this microplankton group in the Southern Hemisphere (Kennett and Srinivasan, 1983; Krashennikov and Basov, 1986; Jenkins, 1992a; Jenkins, 1992b; and others). Similar data on planktonic foraminifers in the Northern Hemisphere are less abundant (Keller, 1978; Keller, 1979; and others).

The analysis of paleogeographic regularities in a planktonic foraminifer distribution allows their assemblages to be used as indicators of paleoclimatic and paleoceanographic environments. This is evident from the confinement of foraminiferal assemblages, which are characterized by a certain number of species and their ratio to particular water masses and climatic zones. When reconstructing paleoceanographic changes based on biogeographic data, information on the confinement of fossil species to particular bioprovinces is used. The distribution characteristics of recent foraminiferal species with well-known ecological features can be ascribed to their fossil counterparts (Barash, 1988). Thus, the concept on the climatic preference of fossil species and the position of foraminifer assemblages in past bioprovinces is formed. The recognition of provinces whose climatic characteristics are predetermined by their geographic setting allows us to elaborate various paleoceanographic reconstructions (Blyum *et al.*, 1987). In the Pacific, similar paleobiogeographic studies were performed by many research-

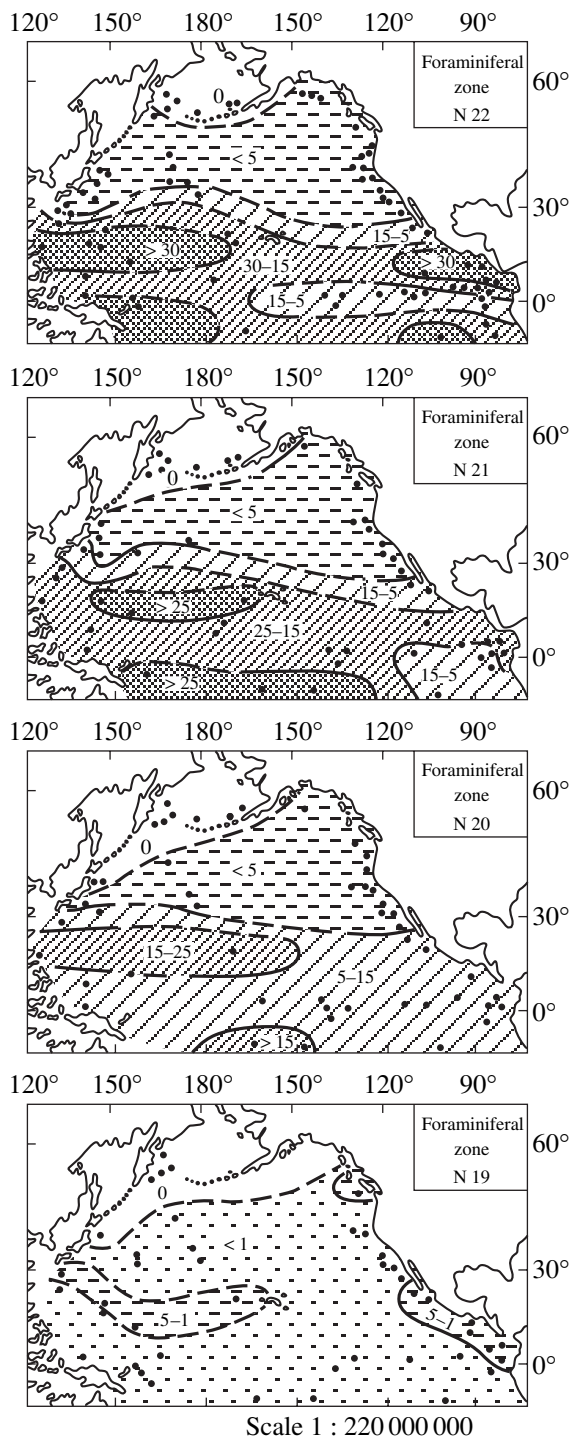


Fig. 1. Maps of distribution areas and percentage of species *Globigerinoides ruber* for time intervals of N19, N20, N21, and N22 foraminiferal zones in Pliocene–Lower Quaternary sediments of the North Pacific.

ers (Blyum and Sokolova, 1989; Blyum *et al.*, 1989; Jenkins, 1992a). The distinguishing feature of the present study is that we used, when defining the peculiarities of the biogeographic distribution of planktonic foraminifers, the quantitative characteristics of their dis-

tribution areas, and this approach provides more reliable and detailed reconstructions.

MATERIALS AND METHODS

Five hundred and seventy samples from the Pliocene–Lower Quaternary sediments drilled in the North Pacific at the latitudes between 15°S and 60°N were available for the analysis. Biogeographic studies were performed for four time intervals, which, according to the newly adopted Pliocene–Quaternary stratigraphic zonation, correspond to foraminiferal zones N19 (100 samples), N20 (122 samples), N21 (155 samples), and N22 (193 samples). Data on zone volumes and age estimates of their boundaries are taken from combined zonal schemes (Krasheninnikov, 1978; Krasheninnikov and Basov, 1986). When specifying the sample ages, we used data on the stratigraphic distribution of planktonic foraminifer species (Kennett and Srinivasan, 1983; Bolli and Saunders, 1985) and datum planes (Berggren *et al.*, 1985; and others).

Approximately 100 foraminiferal species have been defined in the Pliocene–Quaternary sediments throughout the global ocean by various researchers. In the studied samples, which contained foraminifer shells of variable degrees of preservation, we found and identified (based on publications (Bolli and Saunders, 1985; Stainforth *et al.*, 1975; and others)) 65 species and morphological varieties. In doing so, we adopted the taxonomic classification of Kennett and Srinivasan (1983). Some relative species and subspecies were united with the type forms: *Globigerinoides triloba* and *G. immaturus* with *G. quadrilobatus*; *Globigerina* aff. *woodi* and *G. apertura* with *G. decoraperta*; and *Pulleniatina precursor* with *P. primalis*. When interpreting paleobiogeographic characteristics, we considered some genetically related species together: *Globorotalia conomiozea* and *G. conoidea*; *Orbulina universona*, *O. suturalis*, and *O. bilobata*; *Neogloboquadrina dutertrei* and *N. dutertrei blowi*; and *Globigerinella calida* and *G. precalida*.

The quantitative analysis of species in fraction >0.1 mm was performed and the percentage of each of the species was determined in all the samples studied. In doing so, we excluded, in accordance with the method by Ivanova (1988), *Globiberinita glutinata* from the calculations. Using the obtained results, we compiled distribution maps of 59 species and varieties of planktonic foraminifers for the considered time intervals. Figure 1 shows, as an example, the schematic distribution map of *Globigerinoides ruber*. In addition to our own materials, we also used data on planktonic foraminifer distribution in the Pliocene–Lower Quaternary sediments cited in the Deep Sea Drilling Project and Ocean Drilling Program reports, among other works (Keller, 1978, 1979; and others). Using the adopted method, we recalculated quantitative data from these publications and correlated them with our own results. Semiquantitative and qualitative data were used

for specifying the boundaries of species distribution areas.

Further, based on these maps, an analysis of the latitudinal distribution of different species was performed, and schemes showing the distribution area changes with time were compiled. The average percentage was calculated for widely distributed species in every latitudinal belt. Note that, in contrast to this approach, the highest species contents were considered in similar studies on recent planktonic foraminifers (Barash, 1974). The use of average contents in analyzing fossil foraminifers is predetermined by the duration of the studied time intervals (about 1 m.y.), during which significant variations in species contents occur because of the multiple changes in environmental parameters, evolutionary peculiarities of different species, and influence of selective dissolution. The highest contents were used only for compiling the distribution areas of rare species.

The Pliocene–Early Quaternary planktonic foraminifer assemblages in the North Pacific are characterized by their varying degrees of preservation. The influence of dissolution generally increases toward the higher latitudes and in the west–east direction. This corresponds to the distribution patterns of planktonic foraminifers in recent sediments of the North Pacific, which are controlled by the position of foraminiferal lysocline (Belyaeva, 1980; and others). Taking these peculiarities into consideration, we used, when compiling schemes of distribution areas, mainly quantitative data obtained along the meridional profiles throughout the central and northwestern parts of the ocean. For high-latitude species, data from the northeastern Pacific were also considered.

RESULTS AND DISCUSSION

The studies performed allowed us to define the regularities in the biogeographic distribution of foraminiferal species in the Pliocene–Lower Quaternary sediments of the North Pacific and reveal some of the peculiarities in their evolution. Based on the analysis of the stratigraphic ranges of the observed species, we compiled a scheme of their stratigraphic distribution (Fig. 2). One of the earliest stratigraphic schemes compiled for the equatorial-tropical realm of the Indian and Pacific oceans (Parker, 1967) shows stratigraphic ranges of 34 Pliocene–Quaternary species. Most of them do not coincide with those obtained from our materials; sometimes, the discrepancy between data is equal to the volume of the foraminiferal zone. According to our data, species *Globigerinoides ruber*, *G. obliquus*, *Neogloboquadrina dutertrei*, *Globigerina nepenthes*, and others have a wider stratigraphic range, whereas *Globigerinoides fistulosus*, *Pulleniatina spectabilis*, *Globoquadrina venezuelana* and others are characterized by a narrower range. The later stratigraphic schemes show no essential discrepancies with ours, although some differences can be noted. For instance, our scheme

includes species *Globigerina incisa*, *Globoquadrina pseudofoliata*, *Neogloboquadrina pseudoopima*, and *Globorotalia pumilio*, which are absent from the scheme by Kennett and Srinivasan (1983) compiled for the Neogene deposits of the entire Pacific, but based mainly on studies in the southwestern Pacific. Some species, according to our data, have a wider stratigraphic range: *Globigerina decoraperta*, *G. rubescens*, *G. umbilicata*, *Neogloboquadrina dutertrei*, *N. acostaensis*, *Globorotalia unguolata*, *G. limbata*, and *G. pertenuis*. In the scheme by Bolli and Saunders (1985) proposed for lower latitudes and based mostly on foraminiferal data from the Atlantic Ocean, *Globoquadrina pseudofoliata* is absent, according to our data, however, this species should be considered as the equatorial-tropical form. In our scheme, a wider stratigraphic range is characteristic of the species *Neogloboquadrina dutertrei*, *N. acostaensis*, *Pulleniatina obliquiloculata*, *P. primalis*, *Globorotalia inflata*, and *G. crassaformis*, while a narrower range is typical of the species *Globigerina nepenthes*, *Globigerinoides obliquus*, *G. extremus*, *Neogloboquadrina humerosa*, *Globorotalia unguolata*, *G. exilis*, *G. pertenuis*, and *Globigerinella aequilateralis*. These differences can probably be explained by peculiarities in the evolution and ecology of these species, which result in their different stratigraphic ranges in various regions of the global ocean.

The planktonic foraminifer diversity varied during the considered time interval, from 52–53 species in the early Pliocene to 34 species in the Eopleistocene (Fig. 2).

According to Wei and Kennett (1986), who analyzed the evolution of planktonic foraminifers through the Neogene using the data on phylogenetic lineages (Kennett and Srinivasan, 1983), the taxonomic diversity decreased during last 5 m.y. from 59 late Miocene species to 44 late Quaternary species which could have resulted from the acceleration of paleoceanographic oscillations. Dating of evolutionary changes in some phylogenetic lineages of planktonic foraminifers (for instance, in the *Globorotalia inflata*, *G. tumida*, *Sphaeroidinella dehiscens*, and *Globorotalia truncatulinoides* lineages) during the late Neogene also evidence that they occurred almost synchronously with major paleoceanographic events (Malmgren and Berggren, 1987).

Wei and Kennett (1986) showed that the Neogene evolutionary rates of planktonic foraminifers (speciation, extinction, etc.) in three climatic zones (tropical, temperate, and transitional) are similar, although in their opinion, the number of evolutionary events in the tropical zone is always higher because of the higher diversity there. According to our data, during the Pliocene–early Quaternary (N19 to N22 foraminiferal zones), 25 species (13 equatorial-tropical + five tropical + three subtropical) became extinct in the North Pacific and ten species (three + two + five, respectively) appeared. Thus, the taxonomic diversity decreased

Epoch	Eopleistocene	Pliocene			
Age, Ma	0.8	1.8	3.0	4.0 5.0	
Species	Foraminiferal zone	N 22	N 21	N 20	N 19
<i>Gl. calida</i>		---			
<i>Gr. truncatulinoides</i>					
<i>Gs. fistulosus</i>		---	---		
<i>Gr. tosaensis</i>					
<i>Gr. inflata</i>				---	
<i>P. obliquiloculata</i>				---	
<i>Gr. unguolata</i>					---
<i>G. rubescens</i>					---
<i>Gr. crassaformis</i>					---
<i>Gq. dutertrei</i>					---
<i>Gr. tumida</i>					
<i>S. dehiscens</i>					
<i>T. humilis</i>					
<i>St. tokelauae</i>					
<i>Gl. aequilateralis</i>					
<i>Gd. hexagona</i>					
<i>C. nitida</i>					
<i>O. universa</i>					
<i>N. pseudopima</i>					
<i>N. pachyderma</i> dex.					
<i>N. pachyderma</i> sin.					
<i>Gt. uvula</i>					
<i>Gt. glutinata</i>					
<i>G. falconensis</i>					
<i>G. quinqueloba</i>					
<i>G. umbilicata</i>					
<i>G. bulloides</i>					
<i>Gs. congolobatus</i>					
<i>Gs. ruber</i>					
<i>Gs. sacculifer</i>					
<i>Gs. quadrilobatus</i>					
<i>Gr. pumilio</i>					
<i>Gr. scitula</i>					
<i>Gr. menardii</i>					
<i>Gq. pseudofoliata</i>					
<i>Gl. praedigitata</i>		---			
<i>Gq. humerosa</i>		---			
<i>Gq. acostaensis</i>		---			
<i>Gr. flexuosa</i>		---			
<i>G. incisa</i>		---			
<i>G. decoraperta</i>		---			
<i>Gl. praecalida</i>		---			
<i>Gs. obliquus</i>		---			
<i>Gs. extremus</i>		---			
<i>Gr. limbata</i>		---			
<i>Gr. pertenuis</i>		---			
<i>Gr. exilis</i>		---			
<i>Gr. multicamerata</i>		---			
<i>P. primalis</i>		---			
<i>Gr. puncticulata</i>		---			
<i>Gr. conomiozea-Gr. conoidea</i>		---			
<i>D. altispita</i>		---			
<i>Ss. paenedehiscens</i>		---			
<i>Ss. seminulina</i>		---			
<i>Ss. kochi</i>		---			
<i>Gr. margaritae</i>		---			
<i>G. nepenthes</i>		---			
<i>Gq. venezuelana</i>		---			
<i>P. spectabilis</i>		---			
Number of species		34	43	53	52

Fig. 2. Stratigraphic distribution of planktonic foraminifer species in Pliocene–Lower Quaternary sediments of the North Pacific.

mainly at the expense of the extinction of equatorial-tropical and tropical species, whereas the most subtropical species continued to evolve. No single species appeared during the considered interval in the temperate belt.

Other peculiarities in planktonic foraminifer evolution were also defined from paleobiogeographic data in

the intervals studied. Results of these studies are represented in a series of schemes, which reflect the space-time changes in distribution areas of the species (Fig. 3).

Having a large set of new quantitative data, we considered for every species not only the distribution area limits, but also the changes in species concentrations within these areas. Taking into consideration the con-

tents of species in areas of their highest concentrations (see Fig. 3), we defined four groups of Pliocene–Lower Quaternary species differing in abundance: (1) abundant species with concentrations of more than 40% (*Neogloboquadrina pachyderma* sinistral, *Globigerinoides ruber*, and others), (2) common species (40–15%; *Globigerinoides obliquus*, *G. quadrilobatus*, and others), (3) scanty species (15–5%; *Sphaeroidinellopsis seminulina*, *Globigerina quinqueloba*, *Globorotalia foliata*, and others), and (4) rare species (<5%; *Candeina nitida*, *Globorotalia multicamerata*, *Globigerinita uvula*, and others).

Species *Globigerinita glutinata*, by our data, is widespread throughout all considered latitudes, and its highest concentrations make up 50% of the entire foraminiferal assemblage of the equatorial and temperate latitudes (Fig. 3, 59). Many researchers consider this species to be of the recent cosmopolitan form, which shows no distinct relation to particular latitudes and inhabits waters with a wide temperature range. Therefore, we excluded *G. glutinata* from our calculations.

According to spatial distribution, the individual species can be united into three groups, which show the highest concentrations respectively in the lower (0°–25°N), middle (25°–40°N), and higher (40°–60°N) latitudes. According to preliminary analysis, these groups correspond to three major biogeographic provinces of planktonic foraminifers in the World Ocean: equatorial-tropical, subtropical, and temperate-subpolar ones. More detailed paleobiogeographic zonation will be possible after the compilation of maps of the types of Pliocene–Lower Quaternary foraminiferal thanathocoenoses, which is planned to be done in the future. In the southwestern Pacific, Jenkins (1992a) defined five Pliocene provinces, which correspond to the recent ones outlined by Be (1977). As these scientists considered only the qualitative distribution of planktonic foraminifers, the province boundaries were drawn according to the latitudinal limits of species distribution areas which gives no indication of the entire assemblage composition and quantitative proportions of species in the particular province. We have such data, and in further studies, they will form the basis for biogeographic zonation.

The analysis of distribution area dynamics (Fig. 3) allows some features of planktonic foraminifer evolution in the North Pacific during the Pliocene–Early Quaternary to be outlined. Using this information, we identified several types of distribution areas differing in dynamics:

(1) Distribution areas of short-lived species, which appeared and became extinct during the considered time interval (Fig. 4, I). These are *Globorotalia margaritae*, *Globigerinoides fustulosus*, and *Pulleniatina spectabilis* (Fig. 3, 50, 11, and 24, respectively). These species, of low or very low abundance, were confined to the narrow latitudinal belt, and characterized by a

short stratigraphic range within the limits of one or two foraminiferal zones.

(2) Distribution areas of species, which reduced their distribution during the Pliocene–Early Quaternary (Fig. 4, II A and B). There are two groups of species, which passed from the older pre-Pliocene strata and showed either common, or low abundances in the early Pliocene. The first group (A) includes species, which became gradually less abundant during the Pliocene–Early Quaternary and evolved, reducing their distribution areas from the periphery toward the areas of highest concentrations. These are *Globigerina incisa*, *Globigerinoides extremus*, *Globorotalia limbata*, *G. tosaensis*, *G. pumilio*, and *Globoquadrina pseudofoliata* (Fig. 3, 8, 14, 34, 43, 48, and 51, respectively). The other group (B) consists of species displaying similar evolutionary trends, however, they became extinct during the considered time interval: *Globigerina nepenthes*, *G. altispira*, *Globigerinoides obliquus*, *Sphaeroidinellopsis seminulina*, *S. kochi*, and *Globorotalia conomiozea*–*G. conoidea* group (Fig. 3, 5, 15, 19, 20, 47, and 53, respectively). Rare species *Globorotalia multicamerata*, *G. exilis*, *G. pertenuis*, and *Globoquadrina venezuelana* (Fig. 3, 35 to 37 and 52, respectively) became extinct without changes in their distribution areas. *Globoquadrina pseudofoliata* and *Globorotalia tosaensis*, whose distribution areas were reduced during the Pliocene–Early Quaternary, became extinct somewhat later, in the N23 foraminiferal zone (Thompson and Sciarillo, 1978).

(3) Distribution areas of species, whose distribution widened during the Pliocene–Early Quaternary (Fig. 4, III A and B). Two types of extending distribution areas can be distinguished. The first one (A) is represented by older species, which experienced maximum flourishing in the Pliocene. *Globigerinoides ruber*, known since the middle Miocene, became common in the Pliocene and abundant in the Eopleistocene (Fig. 1). The pre-Pliocene species *Globigerinella aequilateralis*, *Globorotalia menardii*, and *G. scitula* also somewhat extended their distribution areas and became more abundant (Fig. 3, 31, 33, and 49, respectively).

The second type (B) is characteristic of species, which appeared in the Pliocene and evolved through the Pliocene–Quaternary. In the Pliocene–early Quaternary, these species became either abundant (*Globigerina rubescens*), or common (*Globorotalia crassaformis*, and *Neogloboquadrina dutertrei*); others remained scanty (*Sphaeroidinella dehiscens* and *Globorotalia truncatulinoides*) (Fig. 3, 7, 46, 28, 17, 41, and 42, respectively).

(4) Distribution areas of genetically related species, which inherited distribution patterns from older species (Fig. 4, IV). Species of the phyletic lineages *Pulleniatina primalis*–*P. obliquiloculata* (Fig. 3, 22 and 23, respectively), *Globorotalia puncticulata*–*G. inflata* (Fig. 3, 45 and 44, respectively), *Globigerina decoraperta*–*G. rebescens* (Fig. 3, 6 and 7, respectively), and

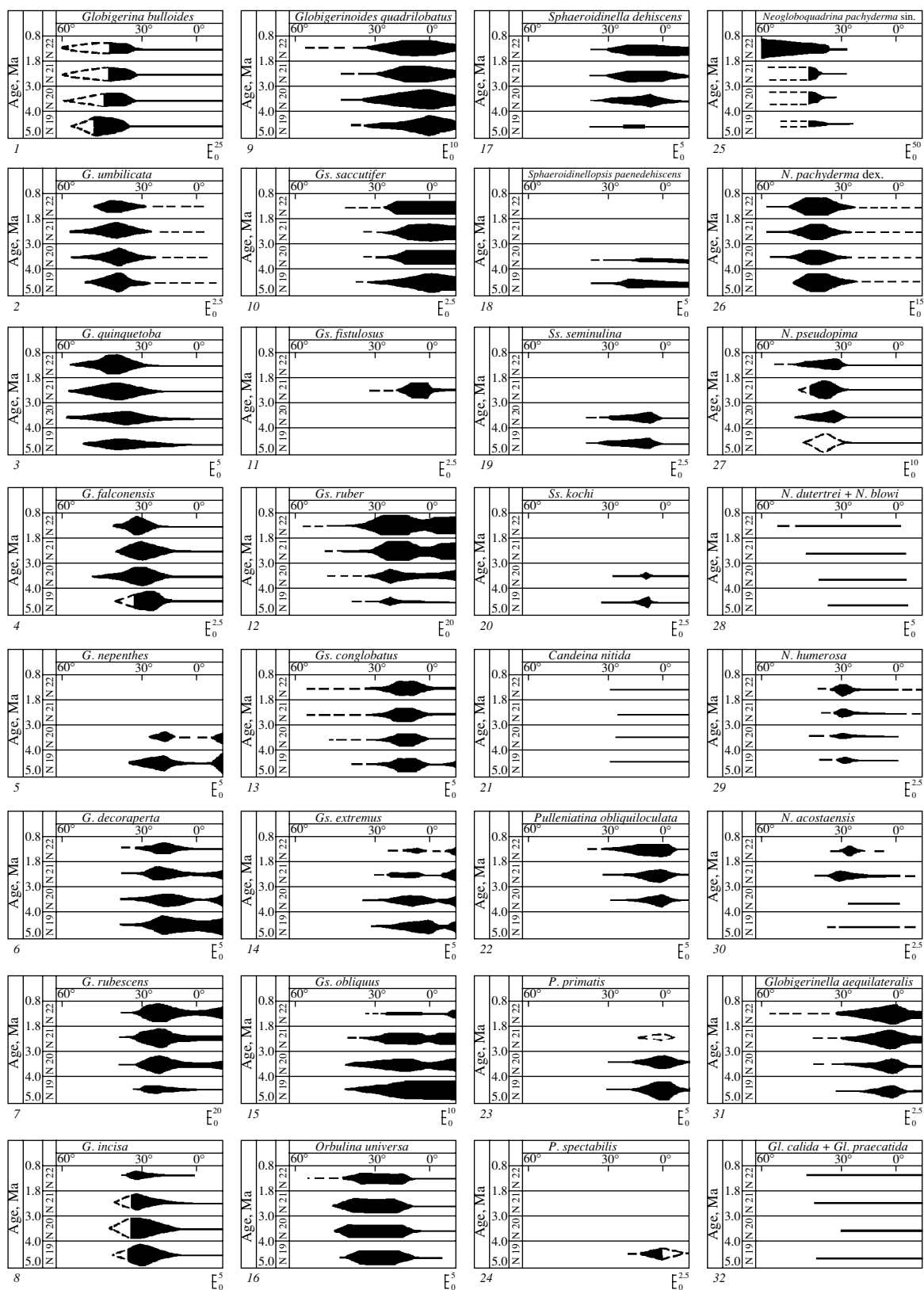


Fig. 3. Schemes of space–time changes in distribution areas of Pliocene–Quaternary planktonic foraminifer species in the North Pacific. Species are grouped according to their generic belonging with due account for species genetic relationships within the group. Scales under figures show the percentage.

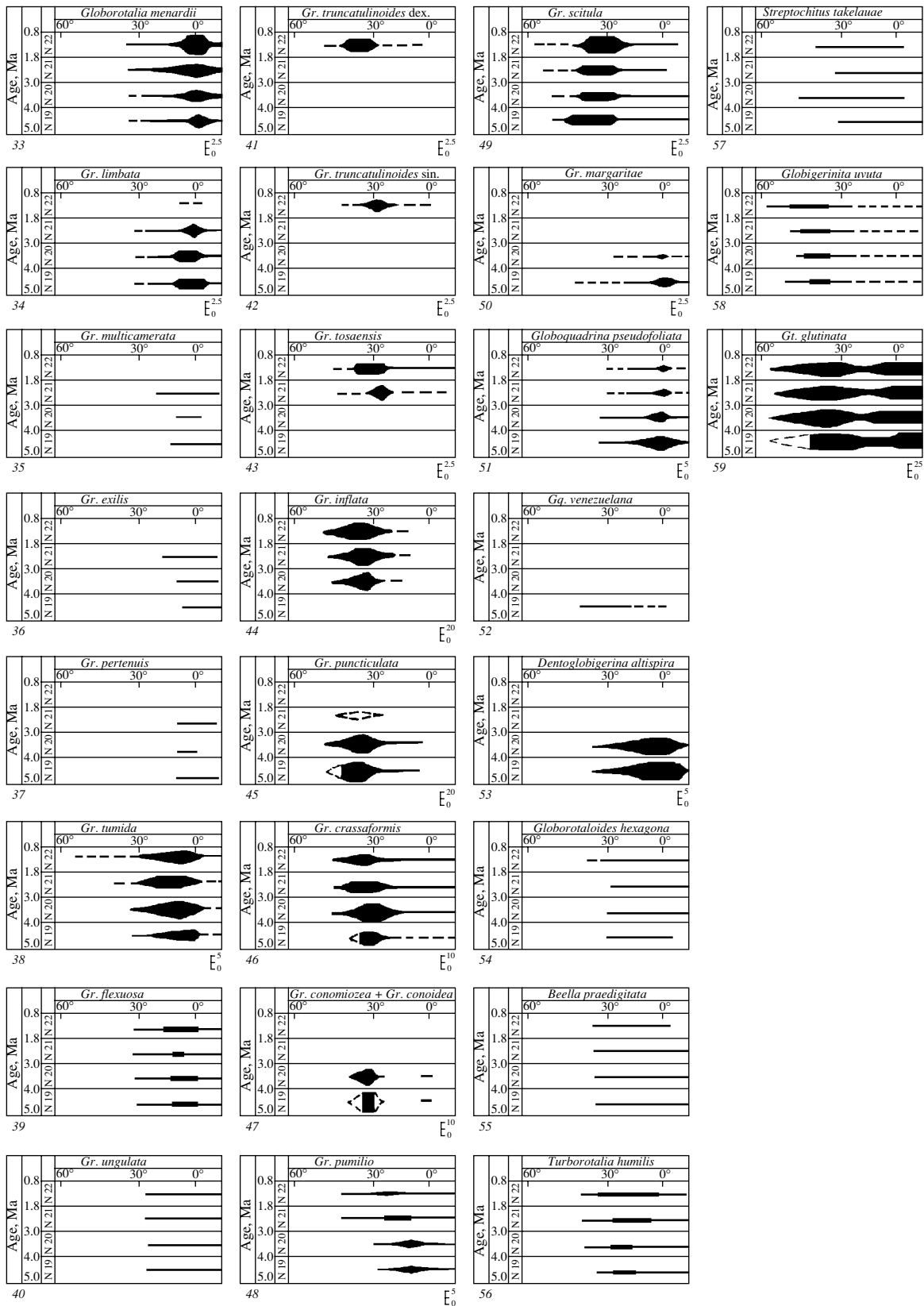


Fig. 3. (Contd.)

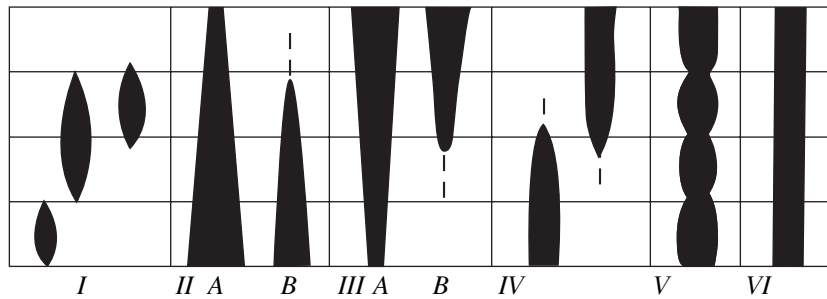


Fig. 4. Types of space–time changes of distribution areas of planktonic foraminifer species.

(I) short-lived; (II) A—reducing the distribution area, B—disappearing; (III) A—widening the distribution area, B—appearing and evolving; (IV) replacing each other; (V) slightly changing the distribution patterns; (VI) with stable distribution area.

Sphaeroidinella paenedehiscens–*S. dehiscens* (Fig. 3, 18 and 17, respectively) are characterized by distribution areas which replace each other, similar abundance, and almost the same latitudinal dispersal and position of areas with their highest concentrations.

The above-described types of distribution areas (Fig. 4, I to IV) are characteristic of the planktonic foraminifer species, which are of significant value for the Pliocene–Lower Quaternary biostratigraphy. As it was shown, the distribution areas of the species, which were evolving during the considered time interval, changed gradually. Prior to final extinction, the species reduced their distribution area from the periphery (lowest abundances) toward the center (highest abundances). The newly appeared and evolving species widened their distribution areas from their centers toward peripheral parts; sometimes, areas of their highest abundances migrated in the same direction.

Thus, the same species could evolve in different latitudinal belts diachronously, and this should be kept in mind when estimating the age of sediments based on datum planes. The most reliable age values for the evolutionary appearance and extinction levels of particular species should be expected from the central part of their distribution areas. The longest duration of the species lifetime is also characteristic of their central part. Other age values can be related to local peculiarities of species dispersal. For instance, according to data by Dowsett (1989), the level of the evolutionary appearance of *Globorotalia truncatulinoides* in the southwestern Pacific is dated at 2.4 Ma, which is 0.5 Ma older than the value determined for this species in the Atlantic and North Pacific (Berggren *et al.*, 1984; and others). These observations show that the age of datum planes should be estimated separately in every climatic belt.

Two more types of space–time changes in distribution areas can be defined in addition to those described above (Fig. 4, IV and V).

(5) Distribution areas of species whose dispersal and abundance changed insignificantly throughout the Pliocene–Early Quaternary. These are species of high latitudes, such as *Globigerina bulloides*, *G. umbilicata*, *G. falconensis*, *Neogloboquadrina pachyderma* sinis-

tral and dextral, and *N. pseudoopima* (Fig. 3, 1, 2, 4, and 25 to 27, respectively). As a rule, such species serve as indicators of certain climatic changes that result in the pulsation of distribution areas and species abundances. The ecological causes which were responsible for the dispersal of the species with distribution areas of this type are crucial for paleoceanographic interpretations.

(6) Distribution areas of species, which had stable dispersal throughout the considered time interval. These are *Globigerinoides quadrilobatus*, *G. sacculifer*, *G. conglobatus*, *Orbulina universa*, and *Globigerinita glutinata* (Fig. 3, 9, 10, 13, 15, and 59, respectively).

For some species with a concentration <5%, it is difficult to note any characteristic feature in their space–time distribution and to refer the distribution areas to any of the described types (Fig. 3, 3, 21, 32, 38, 39, 54, and 56 to 58).

CONCLUSION

Analysis of the stratigraphic distribution and dynamics of distribution areas of planktonic foraminifer species in space and time allowed the following conclusions to be drawn:

(1) In the Pliocene–Lower Quaternary sediments of the North Pacific, 65 species and varieties of planktonic foraminifers were identified and stratigraphic distribution of 60 species was established. Twenty five species of planktonic foraminifers became extinct, and ten species appeared during this time interval. Their diversity decreased from 53 species in the early Pliocene to 34 species in the Eopleistocene.

(2) According to the position of areas with the highest species concentration, we distinguished three groups of species displaying the highest abundances in lower, middle, and higher latitudes. These groups correspond to the three major biogeographic provinces of planktonic foraminifers in the global ocean: equatorial-tropical, subtropical, and temperate-subpolar ones.

(3) Abundant (>40%), common (40–15%), scanty (15–5%), and rare (<5%) species are distinguished in the studied assemblages of planktonic foraminifers.

(4) Changes in abundances and distribution areas of 60 species and varieties of planktonic foraminifers are outlined for time intervals corresponding to the N19, N20, N21, and N22 foraminiferal zones.

(5) Six types of space- and time-dependent changes in the species distribution areas were defined. These types reflect the peculiarities of planktonic foraminifer evolution in the North Pacific.

(6) Prior to extinction, species reduced their distribution areas and abundances from the periphery of the dispersal area toward its center, whereas the newly appeared and evolving species showed an opposite tendency.

(7) Genetically related species (ancestor–descendant) showed similar distribution patterns during their entire lifetime, and their dispersal areas sequentially replaced each other.

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Reviewer I.A. Basov

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